

(NASA-CR-168191) RESEARCH AND DEVELOPMENT
PROGRAM FOR THE DEVELOPMENT OF ADVANCED
TIME-TEMPERATURE DEPENDENT CONSTITUTIVE
RELATIONSHIPS. VOLUME 2: PROGRAMMING
MANUAL Final Report (United Technologies

N84-10614

Unclas
44342

G3/39

1. Report No. NASA CR-168191		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle Research and Development Program for the Development of Advanced Time-Temperature Dependent Constitutive Relationships - Vol. 2 - Programming Manual				5. Report Date July 1983	
				6. Performing Organization Code	
7. Author(s) Dr. Brice N. Cassenti				8. Performing Organization Report No. R83-956077-2	
				10. Work Unit No.	
9. Performing Organization Name and Address United Technologies Research Center 400 Main Street East Hartford, CT 06108				11. Contract or Grant No. NAS3-23273	
				13. Type of Report and Period Covered Contractor Final Report	
12. Sponsoring Agency Name and Address NASA/Lewis Research Center 21000 Brookpark Road Cleveland, Ohio 44135				14. Sponsoring Agency Code	
15. Supplementary Notes Project Manager: R. L. Thompson, Mail Stop 49-6 National Aeronautics and Space Administration Lewis Research Center, 21000 Brookpark Road, Cleveland, Ohio 44135					
16. Abstract This report presents the results of a 10-month research and development program for nonlinear structural modeling with advanced time-temperature constitutive relationships. This program was conducted by the United Technologies Research Center for the NASA-Lewis Research Center under contract NAS3-23273. This manual describes the implementation of the theory, discussed in Vol. 1, in the MARC nonlinear finite element code, and provides instructions for the computational application of the theory.					
17. Key Words (Suggested by Author(s)) Gas Turbine Engines, Creep, Plasticity, Visco-Plasticity, Constitutive Relationship, Thermovisco-Plasticity, Inelastic				18. Distribution Statement Unlimited, Unclassified	
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages	
				22. Price*	

Research and Development Program for the Development
of Advanced Time-Temperature Dependent
Constitutive Relationships

Vol. 2 - Programming Manual

TABLE OF CONTENTS

	<u>Page</u>
1.0 INTRODUCTION.	1
2.0 DESCRIPTION OF THE MARC PROGRAM	2
3.0 IMPLEMENTATION OF VISCOPLASTIC THEORY IN MARC	6
4.0 INTEGRATION OF VISCOPLASTIC EQUATIONS IN SUBROUTINE HYPELA.	9
4.1 Self Adaptive Integration.	9
4.2 Time Independent Terms and Rate of Change of Temperature Terms.	10
4.3 Modifications to Other MARC Subroutines.	11
4.4 HYPELA Control Parameters.	11
4.5 MARC Input Data Set.	13
4.6 Temperature Input.	13
5.0 REFERENCES.	15
FIGURE	16
APPENDICES	17

1.0 INTRODUCTION

The theory described in Vol. 1 has been implemented in the MARC nonlinear finite element code, Ref. 1. Several modifications to the code are required to insure accurate results. The major modification is through the MARC user subroutine HYPELA. Section 2.0 contains a brief description of the MARC code, while Section 3.0 discusses the inputs to subroutine HYPELA. Section 4.0 presents the control parameters and data cards required to efficiently integrate the viscoplastic equations presented in Appendix 14 of Vol. 1.

2.0 DESCRIPTION OF THE MARC PROGRAM

The viscoplastic theories presented in Volume 1 have been incorporated into the MARC general purpose, nonlinear, finite element program, Ref. 1. This program has been developed expressly for nonlinear structural analysis. This computer code involves sophisticated computational algorithms and advanced finite element formulations, but relies on constitutive models not directly applicable to hot section components.

In this contract, as in the previous contract (Ref. 2), the viscoplastic constitutive theories were incorporated into the MARC program by means of an initial stress technique. All of the material nonlinearity in the constitutive equations is incorporated into an initial load vector and treated as a pseudo body force in the finite element equilibrium equations. Because the viscoplastic constitutive theories form a "stiff" system of differential equations, it is necessary to form the incremental constitutive equation appropriate to the finite element load increment by means of a subincrement technique.

In the subincrement technique the finite element load increment is split into a number of equal subincrements and the viscoplastic constitutive theories are integrated over the small subincrements to form an accurate representation of the incremental constitutive equation over the finite element load increment. Integration over each subincrement was accomplished by means of an explicit Euler forward difference method. Provided the subincrements are sufficiently small (so that the stability level of the forward difference method is not exceeded), the technique has been found to work efficiently and accurately, even for large finite element load increments. However, it is difficult for the user to pick efficient subincremental steps, and there is a considerable incentive to use as few subincrements as possible, consistent with the stability of the differential equations comprising the constitutive theory.

In order to understand the flow of information, it is necessary to briefly examine the MARC code operation. A summary of the operation of the MARC nonlinear finite element, taken from Ref. 2, follows.

The principle of virtual work may be used to generate the MARC nonlinear equilibrium equations governing the incremental response of the structure to an increment of load. In evaluating the nonlinear structural response of a component, the program assumes that the load history is divided into a number of incrementally applied load steps. Each load step is sequentially analyzed as a linear matrix problem using an appropriate stiffness matrix and load vector. Although each load step uses linear matrix methods to solve the incremental equilibrium equations, the incremental equilibrium equations themselves are nonlinear since the load vector will depend on the displacement increment obtained in the solution of the incremental equilibrium equations.

The principle of virtual work may be written, for applied external point loads P_i , or displacements u_i , in the form

$$\sum \int_V \delta \epsilon_i^T \sigma_i dV = \delta u_i^T P_i, \quad (1)$$

where the integral extends over the volume, V , of each finite element and the summation sign extends to all the elements in the structure.

In Eq. (1) the virtual displacement vector δu_i is related to the virtual strain vector $\delta \epsilon_i$ through the relationship

$$\delta \epsilon_i = B_{ij} \delta u_j, \text{ or } \delta \epsilon_i^T = \delta u_j^T B_{ij}^T, \quad (2)$$

where B_{ij} is the strain-displacement matrix and the superscript T denotes transposition. Since δu_i is an arbitrary virtual displacement vector, Eqs. (1) and (2) may be written in the form

$$\sum \int_V B_{ij}^T \sigma_j dV = P_i. \quad (3)$$

This relation expresses the equilibrium of the structure when the applied load vector is P_i and the stress vector is σ_i . If an incremental load ΔP_i is applied to the structure and the stress vector changes to $\sigma_i + \Delta \sigma_i$, the relation expressing the equilibrium of the structure at the end of the incremental load application may be written as

$$\sum \int_V B_{ij}^T (\sigma_j + \Delta \sigma_j) dV = P_i + \Delta P_i. \quad (4)$$

Hence, the relation expressing the equilibrium of the structure during the application of the incremental load vector ΔP_i is obtained from Eqs. (3) and (4) by subtraction in the form

$$\sum \int_V B_{ij}^T \Delta \sigma_j dV = \Delta P_i. \quad (5)$$

ORIGINAL PAGE IS
OF POOR QUALITY

The MARC code allows the user to implement very general constitutive relationships into the program by means of the user subroutine HYPELA. Within this subroutine the user must specify the values of the elasticity matrix D_{ij} and the inelastic stress increment vector $\Delta\zeta_i$ in the incremental vector constitutive relationship

$$\Delta\sigma_i = D_{ij}(\Delta\epsilon_j - \delta_j \alpha \Delta\Theta) - \Delta\zeta_i \quad (6)$$

The inelastic stress increment vector $\Delta\zeta_i$ is computed in HYPELA from the viscoplastic constitutive relationships programmed in the Appendices.

In Eq. (6) α denotes the coefficient of thermal expansion and δ_j is the vector Kronecker delta symbol,

$$\delta_j = \begin{cases} 1 & \text{if } 0 \leq j \leq 3 \\ 0 & \text{if } 3 < j \leq 6 \end{cases} \quad (7)$$

For the class of nonlinear visoplastic constitutive relationships under consideration in this contract, the incremental inelastic stress vector $\Delta\zeta_i$ depends in a highly nonlinear manner on the incremental strain vector $\Delta\epsilon_i$. Since $\Delta\epsilon_i = B_{ij} \Delta u_j$, the incremental inelastic stress vector $\Delta\zeta_i$ depends in a highly nonlinear manner on the nodal displacement vector increment Δu_j , so that $\Delta\zeta_i = \Delta\zeta_i(\Delta u_j)$.

Substitution of Eq. (6) into (5) produces the incremental equilibrium equations for MARC in the form,

$$\sum K_{ij} \Delta u_j = \Delta P_i + \Delta R_i + \sum \int_V B_{ij}^T \Delta\zeta_j dV + \sum \int_V B_{ij}^T \delta_j \alpha \Delta\Theta dV, \quad (8)$$

where K_{ij} is the elemental elastic stiffness matrix defined by the relation

$$K_{ij} = \int_V B_{ik}^T D_{kl} B_{lj} dV. \quad (9)$$

The vector ΔR_i is the residual load correction vector or out-of-equilibrium force vector from the preceding load increment,

$$\Delta R_i = P_i - \sum \int_V B_{ij} \sigma_j dV, \quad (10)$$

which is added to the current increment in order to restore the structure to equilibrium. The nonlinearity in the incremental equilibrium relationship, defined in Eq. (8), arises because the inelastic stress increment vector $\Delta\zeta_i$ depends nonlinearly on the displacement increment vector Δu_j . Values of D_{ij} and $\Delta\zeta_j$ appropriate to the current incremental load step are returned to the main program by subroutine HYPELA and the incremental equilibrium relations in Eq. (8) are solved by successive iterations.

The solution of the incremental equilibrium equations in (8) is accomplished within the MARC code by the following algorithm. At the start of the increment the user subroutine HYPELA is entered to determine the elasticity matrix D_{ij} and the incremental inelastic stress vector $\Delta\zeta_i$. On entry to the subroutine the input consists of the strain increment vector $\Delta\epsilon_i$, the temperature increment $\Delta\theta$, the time increment Δt over which the incremental external load vector ΔP_i is applied to the structure, and the values of the stress, strain, temperature and viscoplastic state variables at the beginning of the increment. Since the incremental strain vector, $\Delta\epsilon_i = B_{ij}\Delta u_j$, can only be accurately determined after the solution to the incremental equilibrium relationship in Eq. (8) has yielded the correct incremental solution vector Δu_j , the strain increment vector $\Delta\epsilon_i$ initially used to generate the inelastic stress increment vector $\Delta\zeta_i$ must be estimated. The initial estimate for $\Delta\epsilon_i$ is assumed to be the value obtained for $\Delta\epsilon_i$ in the preceding increment. On exit from subroutine HYPELA the elasticity matrix D_{ij} and the estimated inelastic stress increment vector $\Delta\zeta_j$ are passed into the main program. After the values of D_{ij} and $\Delta\zeta_j$ are obtained for each integration point in the structure, the incremental equilibrium relationship in Eq. (8) is assembled and solved for the incremental node displacement vector Δu_j . The incremental strain vector, $\Delta\epsilon_i = B_{ij}\Delta u_j$, is then computed and compared with the initial guess for $\Delta\epsilon_i$ used to generate the inelastic incremental stress vector $\Delta\zeta_j$. If this incremental strain vector is equal, within a user specified tolerance, to the incremental strain vector used to compute $\Delta\zeta_j$ in the assembly phase, the solution is assumed to have converged. Otherwise, the updated strain increment vector, obtained from the solution of the equilibrium relations in Eq. (8), is passed into subroutine HYPELA, a new vector, $\Delta\zeta_j$, is computed, and the equilibrium equations resolved to yield an improved value of Δu_j and $\Delta\epsilon_i$. The process is repeated until the value of the vector $\Delta\epsilon_i$ on the assembly phase is equal, within a user specified tolerance, to the value of the vector $\Delta\epsilon_i$ on the solution phase. After convergence is achieved, the temperature, stress vector, strain vector and viscoplastic state variables are updated by adding the incremental values generated during the current increment to the values of these variables at the beginning of the increment. The program then passes on to the next load increment where the process is repeated. A flow chart of the iterative procedure required to implement viscoplastic constitutive theories into the MARC program is shown in Fig. 1.

3.0 IMPLEMENTATION OF VISCOPLASTIC THEORY IN MARC

The integration of the viscoplastic theory described in Vol. 1 can be introduced into the MARC code by means of the user subroutine HYPELA. This routine is called at each integration point in each element and supplies the elasticity matrix D_{ij} and the inelastic stress increment vector $\Delta\zeta_j$ to the main program.

The required header cards are:

```

SUBROUTINE HYPELA(D,G,E,DE,S,TEMP, DTEMP,NGENS,N,NN,KC,MAT,NDI,
1NSHEAR)
  DIMENSION D(NGENS,NGENS),G(NGENS),E(NGENS),DE(NGENS),S(NGENS)
  DIMENSION TEMP(1), DTEMP(1)
  :
  FORTRAN CODING
  :
  RETURN
END

```

where

D(NGENS,NGENS)	is the elasticity matrix D_{ij} defined in this subroutine (output argument),
G(NGENS)	is the inelastic stress increment vector $\Delta\zeta_j$ defined in this subroutine (output argument),
E(NGENS)	is the mechanical strain $\epsilon_i - \delta_i \int_0^t \alpha(\xi) [\partial\Theta(\xi)/\partial\xi] d\xi$ at the beginning of the increment (input argument),
DE(NGENS)	is the increment of mechanical strain $\Delta\epsilon_i - \delta_i \alpha \Delta\Theta$ (input argument),
S(NGENS)	is the stress σ_i at the beginning of the increment (input argument),
TEMP(1)	is the temperature Θ at the beginning of the increment (input argument),
TEMP(2)	is the time t at the beginning of the increment (input argument),

TEMP(3)	is the cumulative inelastic strain R at the beginning of the increment (input argument),
TEMP(4) through TEMP(9)	are the values of the inelastic strains, c_1 through c_6 , at the beginning of the increment (input argument),
TEMP(10) through TEMP(15)	are the values of the equilibrium stresses Ω_1 through Ω_6 at the beginning of the increment (input argument),
TEMP(16)	is the number of subincrements used to integrate the last MARC increment,
DTEMP(1)	is the temperature increment $\Delta\theta$ (input argument),
DTEMP(2)	is the time increment Δt (input argument),
DTEMP(3)	is the increment of cumulative inelastic strain ΔR (output argument)
DTEMP(4) through DTEMP(9)	are the incremental values of inelastic strain Δc_1 through Δc_6 (output argument),
DTEMP(10) through DTEMP(15)	are the incremental values of the equilibrium stress $\Delta\Omega_1$ through $\Delta\Omega_6$ (output argument),
DTEMP(16)	is output as zero, since the NSPLIT is updated automatically,
NGENS	is the size of the D_{ij} matrix (NGENS = 3 for plane stress problems, NGENS = 4 for plane strain and axisymmetric problems, NGENS = 6 for three dimensional problems) (input argument),
N	is the finite element number (input argument),
NN	is the integration point number (input argument),
KC	is the layer number in shell or beam problems (input argument),
MAT	is the material identifier (input argument),

NDI

is the number of direct stress components (NDI = 2 for plane stress problems, NDI = 3 for plane strain, axisymmetric and three dimensional problems) (input argument)

NSHEAR

is the number of shear components (NSHEAR = 1 for plane stress, plane strain and axisymmetric problems. NSHEAR = 3 for three dimensional problems) (input argument)

4.0 INTEGRATION OF VISCOPLASTIC EQUATIONS IN SUBROUTINE HYPELA

4.1 Self Adaptive Integration

The values of D_{ij} and $\Delta\zeta_i$ in the incremental constitutive relation,

$$\Delta\sigma_i = D_{ij}(\Delta\epsilon_j - \delta_j \alpha \Delta\theta) - \Delta\zeta_i. \quad (11)$$

are obtained by a subincrement method. Incremental values of the variables $\Delta\theta$, Δt and $(\Delta\epsilon_i - \delta_i \alpha \Delta\theta)$ for the current finite element load increment are split into NSPLIT equal values, and the constitutive equations are integrated over the NSPLIT subincrements to provide accurate values of D_{ij} and $\Delta\zeta_i$. The subroutine HYPELA (Appendix 1) integrates Walker's viscoplastic equations and calls subroutine HYPCON (Appendix 2) to evaluate the material parameters. HYPCON contains the latest estimates for the parameters in the modified Walker's Theory described in Vol. 1. Each load increment in a MARC analysis is divided into NSPLIT subincrements. The integration of the constitutive equations is performed by using forward differences with a step size determined by dividing the MARC load increment by NSPLIT. Subroutine HYPELA performs the integration in two ways: (1) a fixed step size, or (2) a variable step size. In the fixed step size forward difference (KEY equal to one at line 32 of HYPELA), NSPLIT is the same for all MARC load increments and subincrements.

In the variable step size forward difference (KEY equal to zero in line 32 of HYPELA), NSPLIT is determined by the magnitude of the change in a strain measure for every subincrement. The change in the strain measure is defined as

$$E = \Delta R + \frac{\sqrt{3\Delta J_2}}{2\mu} \quad (12)$$

where

$$\Delta R = \sqrt{\frac{2}{3} \Delta C_{ij} \Delta C_{ij}} \quad (13)$$

$$\Delta J_2 = \frac{3}{2} \Delta S_{ij} \Delta S_{ij} \text{ and} \quad (14)$$

the quantity $\Delta \epsilon$ is calculated in line 324 of HYPELA and is stored as variable ERROR0. There are three possible ways to determine NSPLIT. The method depends on the size of ERROR0. If

$$\text{ERROR2} < \text{ERROR0} < \text{ERROR1} \quad (15)$$

Then NSPLIT remains the same for the next subincrement (ERROR1 and ERROR2 are specified in lines 54 and 55 of HYPELA). If

$$\text{ERROR0} < \text{ERROR2} \quad (16)$$

NSPLIT is divided in two for the next subincrement and rounded (up) to the nearest integer. If

$$\text{ERROR0} > \text{ERROR1} \quad (17)$$

then NSPLIT is doubled and the step is recomputed. The value of NSPLIT at the end of the increment is stored in the state variable TEMP(16). The initial value of NSPLIT can be specified in an INITIAL STATE BLOCK in the MARC model definition cards or in line 31 of HYPELA. The maximum value of NSPLIT is specified by MXSPLT (line 57 of HYPELA). If NSPLIT exceeds MXSPLT the message:

"UNABLE TO REDUCE ERROR IN LESS THAN MXSPLT SUBINCREMENTS"

is written where the value of MXSPLT is inserted in the WRITE statement. After this condition is satisfied the integration is performed using a constant step size.

4.2 Time Independent Terms and Rate of Change of Temperature Terms

Two remaining variables must be specified in HYPELA: NONISO (line 64 of HYPELA) and INDEP (line 67 of HYPELA). If

$$\text{NONISO} = 1 \quad (18)$$

the change in temperature with respect to time terms will be included. If

$$\text{NONISO} = 0 \quad (19)$$

these terms will not be included. If

$$\text{INDEP} = 1 \quad (20)$$

the time independent terms will be included. If

$$\text{INDEP} = 0 \quad (21)$$

these terms will not be included.

4.3 Modifications to Other MARC Subroutines

In order to run viscoplastic models in a more efficient manner, the MARC code can be modified to run using a constant inverted stiffness matrix. Such a modification eliminates the requirement to reassemble and invert the stiffness matrix with a subsequent savings in CPU time. This can be accomplished, for example, by:

(1) changing line 65 of subroutine THRUH (Appendix 3) to

LOADUQ = 0 (22)

(2) changing line 116 of subroutine INCDT1 (Appendix 4) to

IASMBL = 0, and

(3) changing line 208 of subroutine INCDT1 to

IASMBL = 0

To insure proper runs only the appropriate lines specifying IASMBL in subroutines INCDT1 and INCDT2 should be changed. For example, if only BOUNDARY CHANGE cards are used in the load incrementation part of the MARC input, then only line 208 of INCDT1 for specifying IASMBL needs to be changed (along with line 65 of THRUH).

Line 753 of the MARC subroutine STEG needs to be changed to that shown in Appendix 5 to insure proper running of the MARC code when using HYPELA.

4.4 HYPELA Control Parameters

The subroutine HYPCON, which calculates the temperature dependent material parameters, is called four times by HYPELA at lines 68, 188, 193 and 198. Each of these calls evaluates the material parameters at a different temperature. The first call determines the elastic constants for which the stiffness matrix is generated, and will be the same on all increments. The second through the fourth calls evaluate the material constants at the median temperature of the subincrement, at the beginning of the subincrement and at the end of the subincrement, respectively.

The stiffness matrix is generated with the elastic constants determined by the temperature variable SFTEMP (see line 59 of HYPELA).

MARC solves the incremental equilibrium Eq. (8) by successive iteration. To see how the equilibrium equation iterations are converging one can pick the integration point, NPRIN, at line 51 of HYPELA, in element number, NELPR, at line 40 of HYPELA, at which the maximum amount of nonlinearity is expected. As subroutine

HYPELA is entered on the assembly phase the routine prints out the strain increment vector $\Delta \epsilon_i$ and the stress increment vector $\Delta \sigma_i$ at integration point NPRIN in element number NELPR. After the equilibrium equations have been solved for the incremental displacement vector Δu_i , subroutine HYPELA is again entered with $\Delta \epsilon_i = B_{ij} \Delta u_j$ and the incremental vectors are printed out on the assembly and solution phase of every successive iteration of the equilibrium equations. In this way the convergence of the solution to the incremental equilibrium equations can be followed. If no printout of the incremental vectors is required, the variable IPR at line 50 of HYPELA, is set equal to zero.

In order to use subroutine HYPELA, several constants must be defined in the subroutine, starting at card number thirty-one (31). These constants are:

MXSPLT	=	maximum number of subincrements allowed,
NELPR	=	element number for printout of incremental stress and strain vectors,
IPR	=	1 if stress-strain increment output is required, 0 if stress-strain increment output is not required
NPRIN	=	integration point number for printout of incremental stress and strain vectors,
NSPLIT	=	number of subincrements per MARC increment,
SFTEMP	=	reference temperature for calculating elastic constants
ERROR2	=	minimum change in strain measure (Eq. 12) allowed before a subincrement step size
ERROR1	=	maximum change in strain measure (Eq. 12) allowed before halving subincrement step size
NONISC	=	1 to include rate of change of temperature terms, and equals zero if these terms are not included
INDEP	=	1 to include time independent terms, and equals zero if these terms are not included.

In Appendices 6, 7 and 8 are listings of the data input to simulate the three thermomechanical fatigue cycles described in Volume 1.

4.5 MARC Input Data Set

In the MARC input data deck two cards are required in the parameter set before the END card. These are:

```
HYPOELAS
STATE VARS          16
```

4.6 Temperature Input

A uniform temperature increment over the structure, together with an appropriate time increment, can be specified with the following cards:

```
THERMAL LOADS
1,
5.0, 2.0
BLANK CARD
```

In the above sequence of cards, the first state variable increment of 5.0 refers to the uniform temperature increment $\Delta\theta = 5^\circ\text{F}$ over the structure. The second state variable increment of 2.0 refers to a time increment of $\Delta t = 2$ seconds. The remainder of the card and the following BLANK card set the remaining fourteen (14) state variable increments to zero. Since the STATE VARS card defines sixteen (16) state variables, MARC expects this number as input. However, only the first two state variables, $\Delta\theta$ and Δt are required as input by HYPELA. The remaining (14) state variable increments are defined within subroutine HYPELA.

If a nonuniform temperature over the structure is required (the usual case), the temperature increments and time increment must be set in user subroutine CREDE. This can be accomplished with the following header cards:

```
SUBROUTINE CREDE(DTDL,M,NSTRES,NEQST,NSTATS)
DIMENSION DTDL(NSTATS,NEQST,NSTRES)
COMMON/FAR/DUM,L
```

N = (where N = number of integration points in element number M)

```
DO 2 II = 1, N
```


R83-956077-2

DTDL(1,1,II) = temperature increment at integration point II

DTDL(2,1,JI) = time increment (can be made a function of load increment number L)

2 CONTINUE
RETURN
END

5.0 REFERENCES

1. MARC General-Purpose Finite Element Program, MARC Corporation, Palo Alto, CA.
2. Walker, K. P.: Research and Development Program for Nonlinear Structural Modeling with Advanced Time-Temperature Dependent Constitutive Relationships. Final Report NASA CR-165533, November 1981.

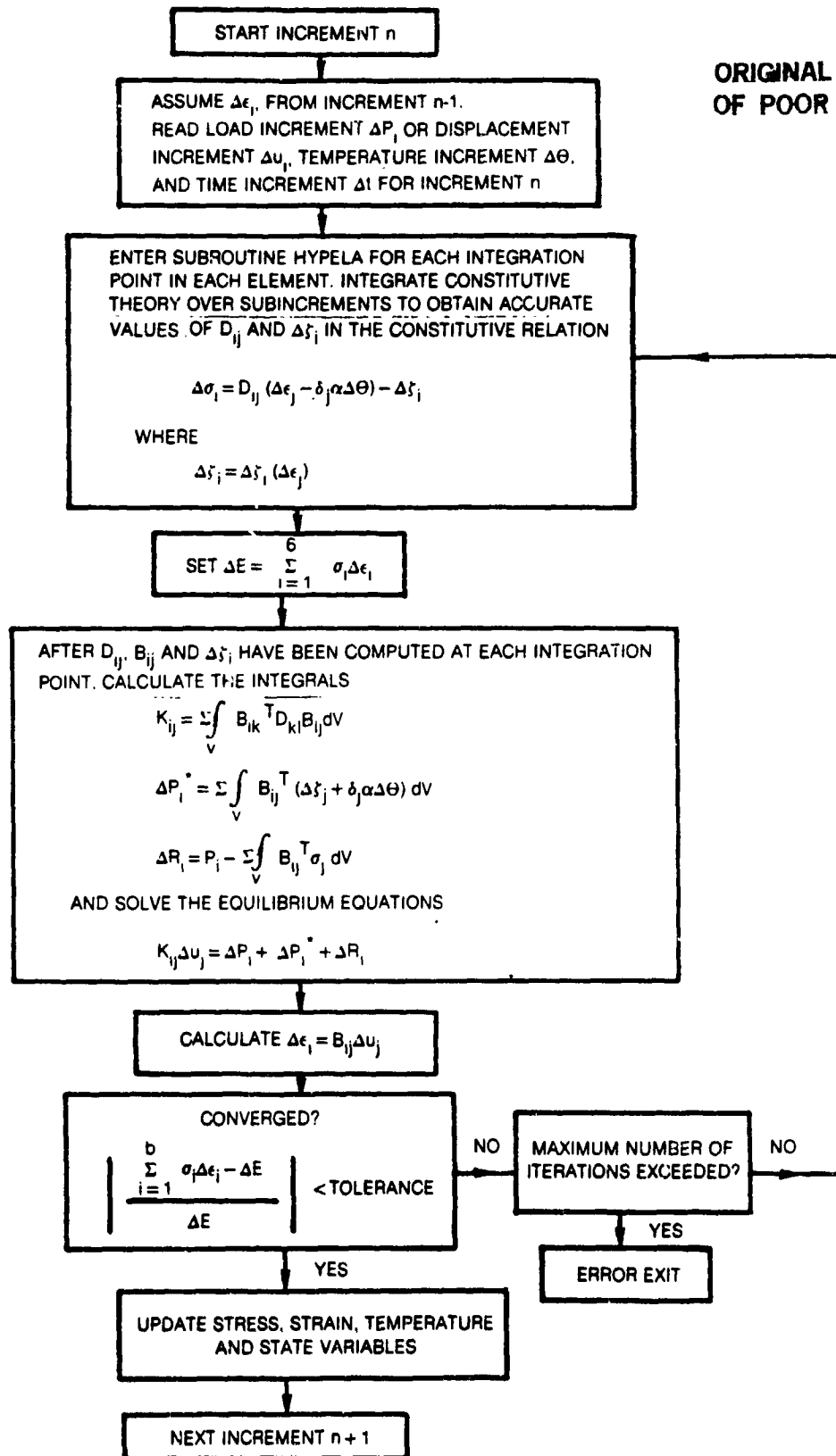


Figure 1. Flow Chart of MARC Iteration Procedure

```

1      SUBROUTINE HYPELA(D,G,E,DE,S,TEMP,DTEMP,NGENS,N,NN,KC,MAT,NDI,
2      INSHEAR)
3      DIMENSION D(NGENS,NGENS),G(NGENS),E(NGENS),DE(NGENS),S(NGENS)
4      DIMENSION TEMP(1),DTEMP(1)
5      DIMENSION DSIG(6),DOMEG(6)
6      DIMENSION SIG(6),OMEG(6),C(6)
7      DIMENSION DC(6),DET(6),OMEGI(6),AB(6)
8      DIMENSION SUMSIG(6),ET(6),DS(6),ETI(6)
9      DIMENSION DEV(6),OV(6),DAB(6),CI(6)
10     COMMON/AKEV/KEVIN
11     COMMON/FAR/DUM,INC
12     COMMON/CDC/ICROUT,NUPTRA,NCPIN,NCYCM,TOLER,XFAC,FLAMB,FRCTOL,MINC,
13     ININST1,NINST2,NDUM,SCALE,NYD,IDESP,NFCQ,FACS,DISPRE,NCYCLE
14     C*****SECOND INVARIANT FUNCTION
15     SINVA(A,B,C,D,E,F)=(A*A+B*B+C*C+2.*(D*D+E*E+F*F))*2./3.
16     1234 CONTINUE
17     C*****
18     C*****THIS SUBROUTINE RETURNS THE ELASTICITY MATRIX D AND INELASTIC STRESS
19     C*****INCREMENT G FOR THE WALKER'S THEORY (B.N.CASSENTI UTRC)
20     C*****USING THE DIFFERENTIAL FORM OF THE THEORY
21     C*****EQUATIONS ARE INTEGRATED USING A FOWARD DIFFERENCE
22     C*****WITH ERROR ESTIMATES FOR REVISING TIME STEPS
23     C*****
24     C
25     FOR SELF ADAPTIVE INTEGRATION SET KEY=0
26     C
27     FOR FIXED STEP INTEGRATION SET KEY=1 AND
28     C
29     C
30     (1) SET NSPLIT IN TEMP(16) THROUGH AN INITIAL STATE BLOCK AND/OR
31     C
32     (2) SET NSPLIT IN THE IF STATEMENT BELOW
33     C
34     NSPLIT=TEMP(16)
35     IF (NSPLIT.LT..999)NSPLIT=16
36     KEY=1
37     IF(N.NE.1) GO TO 7
38     IF(NN.NE.1) GO TO 7
39     IF(NCYCLE.EQ.0) NWALK=0
40     NWALK=NWALK+1
41     NQ=NWALK-2*NCYCLE
42     NQO=NCYCLE-1
43     C*****DETERMINE IF PLANE STRESS,PLANE STRAIN,AXISYMMETRIC,OR 3-D
44     C*****KELTYP=1 FOR PLANE STRAIN AND AXISYMMETRIC PROBLEMS
45     C*****KELTYP=2 FOR PLANE STRESS PROBLEM
46     C*****KELTYP=3 FOR 3-D PROBLEM
47     7 IF(NDI.EQ.3.AND.NSHEAR.EQ.1) KELTYP=1
48     IF(NDI.EQ.2.AND.NSHEAR.EQ.1) KELTYP=2
49     IF(NDI.EQ.3.AND.NSHEAR.EQ.3) KELTYP=3
50     C*****SET UP CONSTANTS
51     IF(INC.EQ.0 .AND. ABS(DTEMP(1)) .LT. 1.E-9)DTEMP(1)=1.E-12
52     IF(INC.EQ.0 .AND. ABS(DTEMP(2)) .LT. 1.E-9)DTEMP(2)=1.E-2
53     NELPR=1
54     IPR=1
55     NPKIN=1
56     IF ((INC+NCYCLE) .NE. 0) NSPLIT=TEMP(16)
57     C
58     ERROR1 IS MAXIMUM ALLOWABLE STRAIN STEP SIZE
59     ERROR1=1.E-4
60     ERROR2=ERROR1/10.
61     C
62     MXSPLT IS THE MAXIMUM VALUE OF NSPLIT ALLOWED
63     MXSPLT=65
64     IF (KEY.EQ. 1) MXSPLT=NSPLIT
65     SFTEMP=940.
66     DEGM=SFTEMP
67     IF (TEMP(1) .GT. 1.E-9) SFTEMP=TEMP(1)
68     C*****NONISO=0 WILL NOT INCLUDE DTEMP/DTIME TERMS
69     C*****NONISO=1 WILL INTERPOLATE TO INCLUDE DTEMP/DTIME TERMS
70     NONISO=0
71     C*****INDEP=0 TIME INDEPENDENT TERMS NOT INCLUDED
72     C*****INDEP=1 TIME INDEPENDENT TERMS ARE INCLUDED
73     INDEP=1
74     CALL HYPCON(INDEP,NONISO,DEGM.

```

```

69      1 EEM,ANUM,AK1M,AK2M,AN1M,AMM,AN1M,AN2M,AN3M,AN4M,AN5M,AN6M,AN7M,
70      2 OMEGOM,AKINDM,SIINFM,DN1DTM,DN2DTM,DOMDTM,
71      3 ANM,ALAMM,AMUM,C1M,C2M,C3M,C4M,C5M)
72 C*****SET ZERO STRAIN INCREMENTS = 1.E-8 TO AVOID DIVISION BY ZERO
73 DESINV=SINV(DE(1),DE(2),DE(3),DE(4),DE(5),DE(6))
74 DO 1 J=1,NGENS
75 IF(DESINV.EQ.0.) DE(J)=1.E-8
76 1 CONTINUE
77 C*****PUT STRESSES AT BEGINNING OF MARC INCREMENT INTO SIGB ARRAY ACCORDING
78 C*****TO ELEMENT TYPE
79 GO TO(801,802,803),KELTYP
80 801 CONTINUE
81 SIG(1)=S(1)
82 SIG(2)=S(2)
83 SIG(3)=S(3)
84 SIG(4)=S(4)
85 SIG(5)=0.
86 SIG(6)=0.
87 GO TO 900
88 802 CONTINUE
89 SIG(1)=S(1)
90 SIG(2)=S(2)
91 SIG(3)=0.
92 SIG(4)=S(3)
93 SIG(5)=0.
94 SIG(6)=0.
95 GO TO 900
96 803 DO 804 J=1,6
97 SIG(J)=S(J)
98 804 CONTINUE
99 900 CONTINUE
100 C*****INITIALIZE STATE VARIABLES ON FIRST ENTRY TO SUBROUTINE. ON SECOND
101 C*****AND SUBSEQUENT ENTRIES SKIP INITIALIZATION.
102 KEVIN=INC+NCYCLE
103 IF(KEVIN.NE.0) GO TO 3
104 IF (TEMP(1) .GT. 1.E-9) SFTEMP=TEMP(1)
105 IF (TEMP(1) .LT. 1.E-9) TEMP(1)=SFTEMP
106 DO 2 J=2,15
107 TEMP(J)=1.E-9
108 2 CONTINUE
109 3 CONTINUE
110 C*****SET STARTING VALUES OF STATE VARIABLES DURING PRESENT MARC INCREMENT
111 DEG=TEMP(1)
112 T=TEMP(2)
113 R=TEMP(3)
114 DO 104 KA=1,6
115 J=KA+3
116 OMEG(KA)=TEMP(J)
117 C(KA)=TEMP(J+6)
118 SUMSIG(KA)=0.
119 104 CONTINUE
120 KSTEP=0
121 ERROR0=0.
122 C*****START INTEGRATION STEP OVER SUBINCREMENT
123 5 SPLIT=NSPLIT
124 KSTEP=KSTEP+1
125 WRITE (6,4271) KSTEP,NSPLIT,ERROR0,T
126 C4271 FORMAT (1H,'KSTEP= ',I5,5X,'NSPLIT= ',I5,5X,'ERROR0= ',1PE10.3,5X
127 C 1,'TIME= ',1PE10.3)
128 IF (NSPLIT .LE. MXSPLT)GOTO4274
129 IF (KEY .EQ. 0) WRITE(6,4273) MXSPLT
130 4273 FORMAT
131 1(1H,'*****'/
132 2 1H,'UNABLE TO REDUCE ERROR IN LESS THAN ',I5,' SUBINCREMENTS'/
133 3 1H,'*****'/)
134 KEY=1
135 4274 IF (ABS(T-(TEMP(2)+DTEMP(2))) .GT. ABS(DTEMP(2)/SPLIT))GOTO6
136 SPLIT=DTEMP(2)/(TEMP(2)+DTEMP(2)-T)
137 IF (ABS((TEMP(2)+DTEMP(2)-T)/DTEMP(2)) .LT. 1.E-3) GOTO420
138 C*****SET TEMPERATURE AND TIME SUBINCREMENTS
139 6 DDEG=DTEMP(1)/SPLIT
140 DT=DTEMP(2)/SPLIT
141 C*****SET STARTING VALUES FOR DEVIATORIC STRESSES
142 PRESS=(SIG(1)+SIG(2)+SIG(3))/3.

```

ORIGINAL PAGE 19
OF POOR QUALITY

ORIGINAL PAGE IS
OF POOR QUALITY

```

143 DO 7777 J=1,6
144 ALPHA=1.
145 IF(J.GT.3)ALPHA=0.
146 DEV(J)=SIG(J)-ALPHA*PRESS
147 7777 CONTINUE
148 C*****PUT SUBINCREMENTS OF TOTAL STRAIN INTO ARRAY DET ACCORDING
149 C*****ELEMENT TYPE
150 GO TO(61,62,63),KELTYP
151 61 CONTINUE
152 DET(1)=DE(1)/SPLIT
153 DET(2)=DE(2)/SPLIT
154 DET(3)=DE(3)/SPLIT
155 DET(4)=0.5*DE(4)/SPLIT
156 DET(5)=0.
157 DET(6)=0.
158 ET(1)=E(1)
159 ET(2)=E(2)
160 ET(3)=E(3)
161 ET(4)=0.5*E(4)
162 ET(5)=0.
163 ET(6)=0.
164 GO TO 71
165 62 DET(1)=DE(1)/SPLIT
166 DET(2)=DE(2)/SPLIT
167 DET(3)=-DET(1)-DET(2)
168 DET(4)=0.5*DE(3)/SPLIT
169 DET(5)=0.
170 DET(6)=0.
171 ET(1)=E(1)
172 ET(2)=E(2)
173 ET(3)=-ET(1)-ET(2)
174 ET(4)=0.5*E(3)
175 DET(5)=0.
176 DET(6)=0.
177 GO TO 71
178 63 CONTINUE
179 DO 64 J=1,6
180 FAC=1.
181 IF(J.GT.3)FAC=0.5
182 DET(J)=FAC*DE(J)/SPLIT
183 ET(J)=FAC*E(J)
184 64 CONTINUE
185 71 CONTINUE
186 C*****COMPUTE TEMPERATURE DEPENDENT MATERIAL CONSTANTS
187 DEGM=DEG+0.5*DDEG
188 CALL HYPCON(INDEP, NONISO, DEGM,
189 1 EE, ANU, AK1, AK2, ANIN, AM, AN1, AN2, AN3, AN4, AN5, AN6, AN7,
190 2 OMEGO, AKIND, SIINF, DN1DT, DN2DT, DOMDT,
191 3 AN, ALAM, AMU, C1D, C2, C3, C4, C5)
192 DEGM=DEG
193 CALL HYPCON(INDEP, NONISO, DEGM,
194 1 EEO, ANUO, AK1O, AK2O, ANINO, AMO, AN1O, AN2O, AN3O, AN4O, AN5O, AN6O, AN7O,
195 2 OMEGOO, AKINDO, SIINFO, DN1DTO, DN2DTO, DOMDTO,
196 3 ANTO, ALAMO, AMUO, C1O, C2O, C3O, C4O, C5O)
197 DEGM=DEG+DDEG
198 CALL HYPCON(INDEP, NONISO, DEGM,
199 1 EE1, ANU1, AK11, AK21, ANIN1, AM1, AN11, AN21, AN31, AN41, AN51, AN61, AN71,
200 2 OMEGO1, AKIND1, SIINF1, DN1DT1, DN2DT1, DOMDT1,
201 3 AN1, ALAM1, AMU1, C11, C21, C31, C41, C51)
202 C*****SET INITIAL VALUES OF EQUILIBRIUM STRESS
203 DENOM=SINV(C(1), C(2), C(3), C(4), C(5), C(6))
204 DENOM=DENOM+1.E-30
205 AB(1)=OMEGO+2.*OMEGO*(C(1)*C(1)+C(4)*C(4)+C(6)*C(6)
206 1+1.E-30)/DENOM
207 AB(2)=OMEGO+2.*OMEGO*(C(4)*C(4)+C(2)*C(2)+C(5)*C(5)
208 1+1.E-30)/DENOM
209 AB(3)=OMEGO+2.*OMEGO*(C(6)*C(6)+C(5)*C(5)+C(3)*C(3)+
210 1+1.E-30)/DENOM
211 AB(4)=2.*OMEGO*(C(1)*C(4)+C(2)*C(4)+C(5)*C(6)+1.E-30)/
212 1DENOM
213 AB(5)=2.*OMEGO*(C(4)*C(6)+C(2)*C(5)+C(3)*C(5)+1.E-30)/
214 1DENOM
215 AB(6)=2.*OMEGO*(C(1)*C(6)+C(4)*C(5)+C(3)*C(6)+1.E-30)/
216 1DENOM

```

```

217      ABSUM=AB(1)+AB(2)+AB(3)
218      DO 7124 J=1,6
219      ALPHA=1.
220      IF(J.GT.3)ALPHA=0.
221      OMEGI(J)=AB(J)-ALPHA*ABSUM/3.
222      7124 CONTINUE
223      C*****COMPUTE DRAG STRESS
224      AK=AK1-AK2*EXP(-AN7*R)
225      C*****COMPUTE INELASTIC STRAIN SUBINCREMENTS
226      DO 67 J=1,6
227      OV(J)=1.5*DEV(J)-OMEG(J)
228      67 CONTINUE
229      ARG1=SINV(OV(1),OV(2),OV(3),OV(4),OV(5),OV(6))
230      ARG1=SQRT(ARG1)
231      IF(ARG1.LE.1.E-10)ARG1=1.E-10
232      ARG2=(ARG1/AK)**AN
233      FAC=(ARG2/ARG1)*DT
234      DO 302 J=1,6
235      DC(J)=FAC*(1.5*DEV(J)-OMEG(J))
236      302 CONTINUE
237      C*****ADD TIME INDEPENDENT PART
238      IF (INDEP.EQ. 0) GOTO68
239      DAJ2=1.-AKIND*.666667*ARG1**2/(SIINF/AK1*AK)**2
240      DWORK=0.
241      DO 6801 J=1,6
242      DWORK=DWORK+SIG(J)*DET(J)*FLOAT(1+J/4)
243      IF (DWORK.LT. 0) DWORK=0
244      FACTOR=(1.-AKIND)*DWORK/(SIINF/AK1*AK)**2/DAJ2
245      DO 6803 J=1,6
246      DC(J)=FACTOR*OV(J)+DC(J)
247      C*****COMPUTE EQUILIBRIUM STRESS SUBINCREMENTS
248      68      OM2=SINV(OMEG(1),OMEG(2),OMEG(3),OMEG(4),OMEG(5),OMEG(6))
249      OM2=SQRT(OM2)
250      DR=SINV(DC(1),DC(2),DC(3),DC(4),DC(5),DC(6))
251      DR=SQRT(DR)
252      DG=(AN3+AN4*EXP(-AN5*R))*DR+AN6*DT*OM2*(AM-1.)
253      DO 303 J=1,6
254      DOME(J)=(AN1+AN2)*DC(J)-DG*(OMEG(J)-OMEGI(J)-AN1*C(J))
255      IF (NONISO.EQ. 0) GOTO303
256      DOME(J)=DOME(J)+(OMEG(J)-OMEGI(J)-AN1*DC(J))*DN2DT*DDEG
257      1+DN1DT*DC(J)*DDEG
258      DDENOM=(C(1)*DC(1)+C(2)*DC(2)+C(3)*DC(3)+
259      1 2.*(C(4)*DC(4)+C(5)*DC(5)+C(6)*DC(6)))
260      DOM=DOMDT*DDEG
261      DOM1=DOM-2.*OMEGO*DDENOM
262      DENOM=SINV(C(1),C(2),C(3),C(4),C(5),C(6))
263      DENOM=DENOM+1.E-30
264      DAB(1)=DOM+2.*DOM1*(C(1)*C(1)+C(4)*C(4)+C(6)*C(6)
265      1+1.E-30)/DENOM
266      DAB(2)=DOM+2.*DOM1*(C(4)*C(4)+C(2)*C(2)+C(5)*C(5)
267      1+1.E-30)/DENOM
268      DAB(3)=DOM+2.*DOM1*(C(6)*C(6)+C(5)*C(5)+C(3)*C(3)+
269      1 1.E-30)/DENOM
270      DAB(4)=2.*DOM1*(C(1)*C(4)+C(2)*C(4)+C(5)*C(6)+1.E-30)/
271      1DENOM
272      DAB(5)=2.*DOM1*(C(4)*C(6)+C(2)*C(5)+C(3)*C(5)+1.E-30)/
273      1DENOM
274      DAB(6)=2.*DOM1*(C(1)*C(6)+C(4)*C(5)+C(3)*C(6)+1.E-30)/
275      1DENOM
276      DAB(1)=DAB(1)+2.*OMEGO*(DC(1)*C(1)+DC(4)*C(4)+DC(6)*C(6)
277      1+1.E-30)/DENOM
278      DAB(2)=DAB(2)+2.*OMEGO*(DC(4)*C(4)+DC(2)*C(2)+DC(5)*C(5)
279      1+1.E-30)/DENOM
280      DAB(3)=DAB(3)+2.*OMEGO*(DC(6)*C(6)+DC(5)*C(5)+DC(3)*C(3)+
281      1 1.E-30)/DENOM
282      DAB(4)=DAB(4)+2.*OMEGO*(DC(1)*C(4)+DC(2)*C(4)+DC(5)*C(6)+1.E-30)/
283      1DENOM
284      DAB(5)=DAB(5)+2.*OMEGO*(DC(4)*C(6)+DC(2)*C(5)+DC(3)*C(5)+1.E-30)/
285      1DENOM
286      DAB(6)=DAB(6)+2.*OMEGO*(DC(1)*C(6)+DC(4)*C(5)+DC(3)*C(6)+1.E-30)/
287      1DENOM
288      DAB(1)=DAB(1)+2.*OMEGO*(C(1)*DC(1)+C(4)*DC(4)+C(6)*DC(6)
289      1+1.E-30)/DENOM
290      DAB(2)=DAB(2)+2.*OMEGO*(C(4)*DC(4)+C(2)*DC(2)+C(5)*DC(5)

```

ORIGINAL PAGE IS
OF POOR QUALITY

ORIGINAL PAGE IS

OF POOR QUALITY

```

291      1+1.E-30)/DENOM
292      DAB(3)=DAB(3)+2.*OMEGA*(C(6)*DC(6)+C(5)*DC(5)+C(3)*DC(3)+
293      1.E-30)/DENOM
294      DAB(4)=DAB(4)+2.*OMEGA*(C(1)*DC(4)+C(2)*DC(4)+C(5)*DC(6)+1.E-30)/
295      1DENOM
296      DAB(5)=DAB(5)+2.*OMEGA*(C(4)*DC(6)+C(2)*DC(5)+C(3)*DC(5)+1.E-30)/
297      1DENOM
298      DAB(6)=DAB(6)+2.*OMEGA*(C(1)*DC(6)+C(4)*DC(5)+C(3)*DC(6)+1.E-30)/
299      1DENOM
300      303 CONTINUE
301      C*****COMPUTE STRESS SUBINCREMENTS
302      IF (KELTYP.EQ.2) DET(3)=(2.*AMU*DC(3)-ALAM*(DET(1)+DET(2)))/(ALAM+2.
303      1*AMU)
304      DVOL0=0.
305      DVOL1=0.
306      DO 809 J=1,6
307      ET1(J)=ET(J)+DET(J)
308      C1(J)=C(J)+DC(J)
309      IF (J.GT. 3) GOTO809
310      DVOL0=DVOL0+ET(J)
311      DVOL1=DVOL1+ET1(J)
312      809 CONTINUE
313      DO 810 J=1,6
314      FAC=FLOAT(1-J/4)
315      SO=ALAM0*DVOL0*FAC+2.*AMU0*(ET(J)-C(J))
316      S1=ALAM1*DVOL1*FAC+2.*AMU1*(ET1(J)-C1(J))
317      DSIG(J)=S1-SO
318      IF (KELTYP.NE. 2) GOTO810
319      DSIGIN=FAC*2.*AMU*ALAM*DC(3)/(ALAM+2.*AMU)-2.*DC(J)*AMU
320      DSIG(J)=DSIGIN+(ALAM+2.*AMU)*FAC*(DVOL1-DVOL0)+2.*AMU*DET(J)
321      810 CONTINUE
322      C IF SELF ADAPTIVE INTEGRATION IS USED THEN CALCULATE STRAIN
323      C STEP, MAKE APPROPRIATE CHANGES TO NSPLIT AND GO TO
324      C CORRESPONDING PROGRAM STEP
325      IF (KEY.EQ. 1) GOTO410
326      ERROR0=SINV(DSIG(1),DSIG(2),DSIG(3),DSIG(4),DSIG(5)
327      1,DSIG(6))
328      ERROR0=SQRT(ERROR0)/EE+DR
329      IF (ERROR0.LT. ERROR2) NSPLIT=(NSPLIT-1)/2+1
330      IF (ERROR0.LT. ERROR1) GOTO410
331      NSPLIT=2*NSPLIT
332      GOTO5
333      C*****UPDATE SUBINCREMENT VARIABLES
334      410 DEG=DEG+DDEG
335      IF (NSPLIT.GT. MXSPLT) NSPLIT=MXSPLT-1
336      R=R+DR
337      DO 113 J=1,6
338      OMEG(J)=OMEG(J)+DOMEQ(J)
339      SIG(J)=SIG(J)+DSIG(J)
340      C(J)=C1(J)
341      ET(J)=ET1(J)
342      SUMSIG(J)=SUMSIG(J)+DSIG(J)
343      113 CONTINUE
344      PRESS=(SIG(1)+SIG(2)+SIG(3))/3.
345      DO 114 J=1,6
346      ALPHA=1.
347      IF (J.GT.3) ALPHA=0.
348      DEV(J)=SIG(J)-ALPHA*PRESS
349      114 CONTINUE
350      C*****END OF SUBINCREMENT LOOP
351      T=T+DT
352      GOTO5
353      C*****PUT ELASTICITY MATRIX IN D AND INELASTIC STRESS INCREMENT IN G
354      420 GO TO(814,815,816),KELTYP
355      814 CONTINUE
356      DO 817 J=1,4
357      DO 817 K=1,4
358      D(J,K)=0.
359      817 CONTINUE
360      DO 818 J=1,3
361      DO 818 K=1,3
362      ALPHA=0.
363      IF (J.EQ.K) ALPHA=1.
364      D(J,K)=CSM+ALPHA*C3M

```


ORIGINAL PAGE IS
OF POOR QUALITY

```

365      818 CONTINUE
366          D(4,4)=C4M
367          GO TO 903
368      815 CONTINUE
369          D(1,1)=C2M
370          D(1,2)=C1M
371          D(2,1)=C1M
372          D(1,3)=0.
373          D(3,1)=0.
374          D(2,2)=C2M
375          D(2,3)=0.
376          D(3,2)=0.
377          D(3,3)=C4M
378          GO TO 903
379      816 CONTINUE
380          DO 819 J=1,6
381          DO 819 K=1,6
382          D(J,K)=0.
383      819 CONTINUE
384          DO 820 J=1,3
385          DO 820 K=1,3
386          ALPHA=0.
387          IF(J.EQ.K) ALPHA=1.
388          D(J,K)=C5M+ALPHA*C3M
389      820 CONTINUE
390          D(4,4)=C4M
391          D(5,5)=C4M
392          D(6,6)=C4M
393      903 CONTINUE
394          DO 821 J=1,NGENS
395          G(J)=SUMSIG(J)
396          IF (KELTYP.EQ. 2 .AND. J.EQ. 3) G(3)=SUMSIG(4)
397          DO 821 K=1,NGENS
398      821 G(J)=G(J)-D(J,K)*DE(K)
399      C*****COMPUTE STRESS AT END OF MARC INCREMENT
400          DO 822 J=1,NGENS
401          SUM=0.
402          DO 823 K=1,NGENS
403          SUM=SUM+D(J,K)*DE(K)
404      823 CONTINUE
405          DS(J)=SUM+G(J)
406      822 CONTINUE
407      C*****PUT STATE VARIABLE INCREMENTS IN TEMP ARRAY FOR NEXT MARC INCREMENT
408          DTEMP(3)=R-TEMP(3)
409          TEMP(16)=NSPLIT
410          DO 923 KA=1,6
411          J=KA+3
412          DTEMP(J)=OMEG(KA)-TEMP(J)
413          DTEMP(J+6)=C(KA)-TEMP(J+6)
414      923 CONTINUE
415          IF(IPR.EQ.0) GO TO 12
416          IF(NELPR.NE.N) GO TO 12
417          IF (NN.NE.NPRIN) GO TO 12
418          WRITE(6,20) INC
419      20 FORMAT(1H INCREMENT ,I5)
420          IF(NQ.EQ.0) WRITE(6,3) NQQ
421          IF(NQ.GT.0) WRITE(6,39) NCYCLE
422      23 FORMAT(55H VALUES OF PARAMETERS DURING SOLUTION OF RECYCLE NUMBER,
423      1I5)
424      39 FORMAT(55H VALUES OF PARAMETERS DURING ASSEMBLY OF RECYCLE NUMBER,
425      1I5)
426          WRITE(6,29)
427      29 FORMAT(18H STRAIN INCREMENTS)
428          WRITE(6,30) (DE(J),J=1,NGENS)
429      30 FORMAT(1P6E15.6)
430          WRITE(6,31)
431      31 FORMAT(18H STRESS INCREMENTS)
432          WRITE(6,30) (DS(J),J=1,NGENS)
433      12 RETURN
434      C      DEBUG SUBTRACE,UNIT(25),SUBCHK,INIT
435      C      AT 1234
436      END

```

APPENDIX 2. SUBROUTINE HYPCON

ORIGINAL PAGE 19
OF POOR QUALITY

```

1  SUBROUTINE HYPCON(INDEP, NONISO, DEGM,
2  1 EE, ANU, AK1, AK2, ANIN, AM, AN1, AN2, AN3, AN4, AN5, AN6, AN7,
3  2 OMEGO, AKIND, SIINF, DN1DT, DN2DT, DOMDT,
4  3 AN, ALAM, AMU, C1, C2, C3, C4, C5)
5  C THIS SUBROUTINE IS CALLED BY HYPELA TO CALCULATE ALL OF THE
6  C TEMPERATURE DEPENDENT MATERIAL CONSTANTS
7  DIMENSION TABT(6), EET(6), ANUT(6), AK1T(6), ANINT(6), AMT(6), AN1T(6)
8  DIMENSION AN2T(6), AN3T(6), AN4T(6), AN5T(6), AN6T(6), AN7T(6), AK2T(6)
9  DIMENSION OMEGOT(6)
10 DIMENSION AKINDT(6), SIINF(6)
11 DATA TABT/800., 1000., 1200., 1400., 1600., 1800./
12 DATA EET/26.E6, 24.E6, 24.E6, 22.6E6, 18.6E6, 13.2E6/
13 DATA ANUT/0.322, 0.328, 0.334, 0.339, 0.345, 0.351/
14 DATA AK1T/50931., 75631., 95631., 110696., 91505., 59292./
15 DATA AK2T/0., 0., 0., 0., 0., 0./
16 DATA ANINT/.059, .059, .079, .1497, .195, .223/
17 DATA AMT/1.158, 1.158, 1.158, 1.158, 1.158, 1.158/
18 DATA AN1T/0., 0., 0., 0., 0., 0./
19 DATA AN2T/1.E7, 1.9E7, 1.5E7, 2.E7, 5.E6, 1.E6/
20 DATA AN3T/250., 320., 781.2, 1178.6, 672.6, 312.5/
21 DATA AN4T/0., 0., 0., 0., 0., 0./
22 DATA AN5T/0., 0., 0., 0., 0., 0./
23 DATA AN6T/0., 0., 0., 0., 8.977E-4, 2.733E-3/
24 DATA AN7T/0., 0., 0., 0., 0., 0./
25 DATA OMEGOT/0., 0., -2000., -2000., -1434., -1200./
26 DATA AKINDT/0., 0., 0., 0., 0., 0./
27 DATA SIINF/48.E3, 48.E3, 60.E3, 1.E10, 1.E10, 1.E10/
28 NTP=6
29 NTPM1=NTP-1
30 TDIF=TABT(2)-TABT(1)
31 L1=DEGM
32 L2=TABT(1)-TDIF
33 L3=TDIF
34 IT=(L1-L2)/L3
35 IF(IT.LT.1) IT=1
36 IF(IT.GT.NTPM1) IT=NTPM1
37 FAC=(DEGM-TABT(IT))/TDIF
38 EE=(EET(IT+1)-EET(IT))*FAC+EET(IT)
39 ANU=(ANUT(IT+1)-ANUT(IT))*FAC+ANUT(IT)
40 AK1=(AK1T(IT+1)-AK1T(IT))*FAC+AK1T(IT)
41 AK2=(AK2T(IT+1)-AK2T(IT))*FAC+AK2T(IT)
42 ANIN=(ANINT(IT+1)-ANINT(IT))*FAC+ANINT(IT)
43 AM=(AMT(IT+1)-AMT(IT))*FAC+AMT(IT)
44 AN1=(AN1T(IT+1)-AN1T(IT))*FAC+AN1T(IT)
45 AN2=(AN2T(IT+1)-AN2T(IT))*FAC+AN2T(IT)
46 AN3=(AN3T(IT+1)-AN3T(IT))*FAC+AN3T(IT)
47 AN4=(AN4T(IT+1)-AN4T(IT))*FAC+AN4T(IT)
48 AN5=(AN5T(IT+1)-AN5T(IT))*FAC+AN5T(IT)
49 AN6=(AN6T(IT+1)-AN6T(IT))*FAC+AN6T(IT)
50 AN7=(AN7T(IT+1)-AN7T(IT))*FAC+AN7T(IT)
51 OMEGO=(OMEGOT(IT+1)-OMEGOT(IT))*FAC+OMEGOT(IT)
52 IF (INDEP.EQ. 0) GOTO65
53 AKIND=(AKINDT(IT+1)-AKINDT(IT))*FAC+AKINDT(IT)
54 SIINF=(SIINF(IT+1)-SIINF(IT))*FAC+SIINF(IT)
55 65 IF (NONISO.EQ. 0) GOTO73
56 DN1DT=(AN1T(IT+1)-AN1T(IT))/TDIF/(AN1+1.E-6)
57 DN2DT=(AN2T(IT+1)-AN2T(IT))/TDIF/(AN2+1.E-6)
58 DOMDT=(OMEGOT(IT+1)-OMEGOT(IT))/TDIF/(OMEGO+1.E-6)
59 73 CONTINUE
60 AN=1./ANIN
61 ALAM=EE*ANU/((1.-2.*ANU)*(1.+ANU))
62 AMU=(1.-2.*ANU)*ALAM/(2.*ANU)
63 C1=2.*AMU*ALAM/(ALAM+2.*AMU)
64 C2=4.*AMU*(ALAM+AMU)/(ALAM+2.*AMU)
65 C3=2.*AMU
66 C4=AMU
67 C5=ALAM
68 RETURN

```

69 C DEBUG SUBTRACE,UNIT(25),SUBCHK,INIT
70 C AT 1234
71 END

ORIGINAL PAGE IS
OF POOR QUALITY

APPENDIX 3. SUBROUTINE THRUH

ORIGINAL PAGE 13
OF POOR QUALITY

```

•
•
59      101 CALL GMPRD(S,E1,DSEG,1,NGENS,1)
60      CALL SCLA(B,0.,NGENS,NGENS,0)
61      CALL SCLA(GF,0.,NGENS,1,0)
62      C  USER SUPPLIED HYPOELASTIC CONSTITUTIVE THEORY
63      C * * * * *
64      CALL HYPELA(B,GF,EELAS,E1,S,DT,DTD,NGENS,M,NNN,KC,MAT,NDI,NSHEAR)
65      LOADUQ=1
66      C  TOTAL ELASTIC STRAINS
67      C * * * * *
68      CALL GMADD(EELAS,E1,EELAS,NGENS,1)
69      C  INCREMENTAL STRESS COMPONENTS
70      C * * * * *
•
•

```

APPENDIX 4. SUBROUTINE INCDT1

ORIGINAL PAGE 19
OF POOR QUALITY

```

•
•
204      16  CONTINUE
205      161 CONTINUE
206      C
207      C**** BOUNDARY CHANGE
208             IASMBL=1
209             READ(5,103)CARD
210             CALL INTAC(CARD,ICARD,3,JBAD)
211             IF(JBAD.EQ.1)GO TO 110
212             NEWBC=ICARD(1)
213             IFLAG=ICARD(2)
214             IF(IFLAG.EQ.1) WRITE(6,1613)
215      1613 FORMAT(63H0FOLLOWING INFORMATION APPLIES TO HARMONIC RESPONSE CALC
•
•

```

APPENDIX 5. SUBROUTINE STEG

ORIGINAL PAGE IS
OF POOR QUALITY

```

741 399 CONTINUE
742   LA1=MMS4+ISIGXX
743   LA2=LMS1+IGSIG
744   IF(IHRESP.EQ.1)LA2=IGSIG1
745   IF(ISHELL.EQ.1)GO TO 617
746   IF(JTYPE.EQ.52)GO TO 620
747   IF(IHRESP.EQ.1) GO TO 618
748   DSEGAA=ABS(DSEG)
749   DSEGEA=DSEGE
750   DSEGA=DSEG
751   IF(ICREEP.EQ.1.OR.ITHERM.GT.0)CALL TPSMA(VARS(1B1),VARS(IECRP1),
752   I VARS(IFCRP),1.,NGEN1,NGEN1,1)
753   IF(IPELA.EQ.1)
754   *CALL GMSUB(VARS(IFCRP),VARS(IGF),VARS(IFCRP),NGEN1,1)
755   IF(IHERED.EQ.0) GO TO 310
756   IF(MATV.EQ.0.OR.IVSCFN.NE.2) GO TO 310
757   IVS=IVNSER+MATV-1
758   NVSER=INTS(IVS)
759   IF(NVSER.EQ.0) GO TO 310
760   IVD=IVDSIZ+MATV-1
761   NVDSIZ=INTS(IVD)
762   CALL GMADD(VARS(IFCRP),VARS(IGFV2),VARS(IFCRP),NVDSIZ,1)
763   310 CONTINUE
764   618 CONTINUE

```

APPENDIX 6. DATA INPUT FOR CLOSED SYMMETRIC TMF LOOP

1	TITLE	THERMOMECHANICAL LOOP NO. 1 WITH FUNCTIONAL THEORY									
2	SIZING	15000	4	9	9	2	10				
3	POST	2									
4	ALL POINTS										
5	INPUT TAPE	1									
6	HYPOELAS										
7	STATE VARS	16									
8	NO LOADCOR	1									
9	RESTART										
10	END										
11	MESH2D										
12	BLOCKS										
13	1	4	10	1	1	9	6				
14	DEFINE										
15	1	2	2	1	2	3	4				
16	BOUNDARY										
17	1	1.									
18	2	1.	1.								
19	3	0.	1.								
20	4										
21	CONSTRAINT										
22	2										
23	1	3	1								
24	1	4	2								
25	MERGE										
26	.0005										
27	GENERATE										
28	CONNECTIVITY										
29	1										
30	COORDINATES										
31	1										
32	BOUNDARY CONDITIONS										
33	0	1	1								
34	BOUNDARY CONDITIONS										
35	1,										
36	1,3,1,1,1.E-8										
37	THERMAL LOADS										
38	1,										
39	0.,1.E-8										
40											
41	PROPERTY										
42	1										
43	26.0E6	.322	0.E-5								
44	1	4									
45	POST										
46	2	16	16								
47	1										
48	11										
49	PRINT CHOICE										
50	1										
51	1										

ORIGINAL PAGE 13
OF POOR QUALITY

ORIGINAL PAGE 13
OF POOR QUALITY

52 CONTROL
53 49,15,1,0
54 .05
55 RESTART
56 1,1,0,8,8
57 INITIAL STATE
58 1,1,1
59 1,4,1,4
60 800.
61 END OPTION
62 BOUNDARY CHANGE
63 3,
64 7,1,1, .001239
65 8,2,1, .001239
66 9,3,1, .001239
67 THERMAL LOADS
68 1,
69 3.4,1.250000
70
71 CONTINUE
72 BOUNDARY CHANGE
73 3,
74 7,1,1, -.000032
75 8,2,1, -.000032
76 9,3,1, -.000032
77 THERMAL LOADS
78 1,
79 10.2,1.250000
80
81 CONTINUE
82 BOUNDARY CHANGE
83 3,
84 7,1,1, -.000053
85 8,2,1, -.000053
86 9,3,1, -.000053
87 THERMAL LOADS
88 1,
89 16.8,1.250000
90
91 CONTINUE
92 BOUNDARY CHANGE
93 3,
94 7,1,1, -.000072
95 8,2,1, -.000072
96 9,3,1, -.000072
97 THERMAL LOADS
98 1,
99 23.1,1.250000
100
101 CONTINUE
102 BOUNDARY CHANGE
103 3,
104 7,1,1, -.000091
105 8,2,1, -.000091
106 9,3,1, -.000091
107 THERMAL LOADS
108 1,
109 29.1,1.250000
110
111 CONTINUE
112 BOUNDARY CHANGE
113 3,
114 7,1,1, -.000108
115 8,2,1, -.000108
116 9,3,1, -.000108
117 THERMAL LOADS
118 1,
119 34.5,1.250000
120
121 CONTINUE

122 BOUNDARY CHANGE
123 3,
124 7,1,1, -.000123
125 8,2,1, -.000123
126 9,3,1, -.000123
127 THERMAL LOADS
128 1,
129 39.3,1.250000
130
131 CONTINUE
132 BOUNDARY CHANGE
133 3,
134 7,1,1, -.000136
135 8,2,1, -.000136
136 9,3,1, -.000136
137 THERMAL LOADS
138 1,
139 43.5,1.250000
140
141 CONTINUE
142 BOUNDARY CHANGE
143 3,
144 7,1,1, -.000147
145 8,2,1, -.000147
146 9,3,1, -.000147
147 THERMAL LOADS
148 1,
149 46.9,1.250000
150
151 CONTINUE
152 BOUNDARY CHANGE
153 3,
154 7,1,1, -.000155
155 8,2,1, -.000155
156 9,3,1, -.000155
157 THERMAL LOADS
158 1,
159 49.5,1.250000
160
161 CONTINUE
162 BOUNDARY CHANGE
163 3,
164 7,1,1, -.000160
165 8,2,1, -.000160
166 9,3,1, -.000160
167 THERMAL LOADS
168 1,
169 51.3,1.250000
170
171 CONTINUE
172 BOUNDARY CHANGE
173 3,
174 7,1,1, -.000163
175 8,2,1, -.000163
176 9,3,1, -.000163
177 THERMAL LOADS
178 1,
179 52.2,1.250000
180
181 CONTINUE
182 BOUNDARY CHANGE
183 3,
184 7,1,1, -.000163
185 8,2,1, -.000163
186 9,3,1, -.000163
187 THERMAL LOADS
188 1,
189 52.2,1.250000
190
191 CONTINUE
192 BOUNDARY CHANGE
193 3,

194 7,1,1, -.000160
 195 8,2,1, -.000160
 196 9,3,1, -.000160
 197 THERMAL LOADS
 198 1
 199 51.3,1.250000
 200
 201 CONTINUE
 202 BOUNDARY CHANGE
 203 3,
 204 7,1,1, -.000155
 205 8,2,1, -.000155
 206 9,3,1, -.000155
 207 THERMAL LOADS
 208 1
 209 49.5,1.250000
 210
 211 CONTINUE
 212 BOUNDARY CHANGE
 213 3,
 214 7,1,1, -.000147
 215 8,2,1, -.000147
 216 9,3,1, -.000147
 217 THERMAL LOADS
 218 1
 219 46.9,1.250000
 220
 221 CONTINUE
 222 BOUNDARY CHANGE
 223 3,
 224 7,1,1, -.000136
 225 8,2,1, -.000136
 226 9,3,1, -.000136
 227 THERMAL LOADS
 228 1
 229 43.5,1.250000
 230
 231 CONTINUE
 232 BOUNDARY CHANGE
 233 3,
 234 7,1,1, -.000123
 235 8,2,1, -.000123
 236 9,3,1, -.000123
 237 THERMAL LOADS
 238 1
 239 39.3,1.250000
 240
 241 CONTINUE
 242 BOUNDARY CHANGE
 243 3,
 244 7,1,1, -.000108
 245 8,2,1, -.000108
 246 9,3,1, -.000108
 247 THERMAL LOADS
 248 1
 249 34.5,1.250000
 250
 251 CONTINUE
 252 BOUNDARY CHANGE
 253 3,
 254 7,1,1, -.000091
 255 8,2,1, -.000091
 256 9,3,1, -.000091
 257 THERMAL LOADS
 258 1
 259 29.1,1.250000
 260
 261 CONTINUE
 262 BOUNDARY CHANGE
 263 3,
 264 7,1,1, -.000072
 265 8,2,1, -.000072

266 9,3,1, -.000072
 267 THERMAL LOADS
 268 1
 269 23.1,1.250000
 270
 271 CONTINUE
 272 BOUNDARY CHANGE
 273 3,
 274 7,1,1, -.000053
 275 8,2,1, -.000053
 276 9,3,1, -.000053
 277 THERMAL LOADS
 278 1
 279 16.8,1.250000
 280
 281 CONTINUE
 282 BOUNDARY CHANGE
 283 3,
 284 7,1,1, -.000032
 285 8,2,1, -.000032
 286 9,3,1, -.000032
 287 THERMAL LOADS
 288 1
 289 10.2,1.250000
 290
 291 CONTINUE
 292 BOUNDARY CHANGE
 293 3,
 294 7,1,1, -.000011
 295 8,2,1, -.000011
 296 9,3,1, -.000011
 297 THERMAL LOADS
 298 1
 299 3.4,1.250000
 300
 301 CONTINUE
 302 BOUNDARY CHANGE
 303 3,
 304 7,1,1, .000011
 305 8,2,1, .000011
 306 9,3,1, .000011
 307 THERMAL LOADS
 308 1
 309 -3.4,1.250000
 310
 311 CONTINUE
 312 BOUNDARY CHANGE
 313 3,
 314 7,1,1, .000032
 315 8,2,1, .000032
 316 9,3,1, .000032
 317 THERMAL LOADS
 318 1
 319 -10.2,1.250000
 320
 321 CONTINUE
 322 BOUNDARY CHANGE
 323 3,
 324 7,1,1, .000053
 325 8,2,1, .000053
 326 9,3,1, .000053
 327 THERMAL LOADS
 328 1
 329 -16.8,1.250000
 330
 331 CONTINUE
 332 BOUNDARY CHANGE
 333 3,
 334 7,1,1, .000072
 335 8,2,1, .000072
 336 9,3,1, .000072
 337 THERMAL LOADS
 338 1,

ORIGINAL PAGE IS
OF POOR QUALITY

339 -23.1,1.250000
340
341 CONTINUE
342 BOUNDARY CHANGE
343 3,
344 7,1,1, .000091
345 8,2,1, .000091
346 9,3,1, .000091
347 THERMAL LOADS
348 1,
349 -29.1,1.250000
350
351 CONTINUE
352 BOUNDARY CHANGE
353 3,
354 7,1,1, .000108
355 8,2,1, .000108
356 9,3,1, .000108
357 THERMAL LOADS
358 1,
359 -34.5,1.250000
360
361 CONTINUE
362 BOUNDARY CHANGE
363 3,
364 7,1,1, .000123
365 8,2,1, .000123
366 9,3,1, .000123
367 THERMAL LOADS
368 1,
369 -39.3,1.250000
370
371 CONTINUE
372 BOUNDARY CHANGE
373 3,
374 7,1,1, .000136
375 8,2,1, .000136
376 9,3,1, .000136
377 THERMAL LOADS
378 1,
379 -43.5,1.250000
380
381 CONTINUE
382 BOUNDARY CHANGE
383 3,
384 7,1,1, .000147
385 8,2,1, .000147
386 9,3,1, .000147
387 THERMAL LOADS
388 1,
389 -46.9,1.250000
390
391 CONTINUE
392 BOUNDARY CHANGE
393 3,
394 7,1,1, .000155
395 8,2,1, .000155
396 9,3,1, .000155
397 THERMAL LOADS
398 1,
399 -49.5,1.250000
400
401 CONTINUE
402 BOUNDARY CHANGE
403 3,
404 7,1,1, .000160
405 8,2,1, .000160
406 9,3,1, .000160
407 THERMAL LOADS
408 1,
409 -51.3,1.250000
410

411 CONTINUE
412 BOUNDARY CHANGE
413 3,
414 7,1,1, .000163
415 8,2,1, .000163
416 9,3,1, .000163
417 THERMAL LOADS
418 1,
419 -52.2,1.250000
420
421 CONTINUE
422 BOUNDARY CHANGE
423 3,
424 7,1,1, .000163
425 8,2,1, .000163
426 9,3,1, .000163
427 THERMAL LOADS
428 1,
429 -52.2,1.250000
430
431 CONTINUE
432 BOUNDARY CHANGE
433 3,
434 7,1,1, .000160
435 8,2,1, .000160
436 9,3,1, .000160
437 THERMAL LOADS
438 1,
439 -51.3,1.250000
440
441 CONTINUE
442 BOUNDARY CHANGE
443 3,
444 7,1,1, .000155
445 8,2,1, .000155
446 9,3,1, .000155
447 THERMAL LOADS
448 1,
449 -49.5,1.250000
450
451 CONTINUE
452 BOUNDARY CHANGE
453 3,
454 7,1,1, .000147
455 8,2,1, .000147
456 9,3,1, .000147
457 THERMAL LOADS
458 1,
459 -46.9,1.250000
460
461 CONTINUE
462 BOUNDARY CHANGE
463 3,
464 7,1,1, .000136
465 8,2,1, .000136
466 9,3,1, .000136
467 THERMAL LOADS
468 1,
469 -43.5,1.250000
470
471 CONTINUE
472 BOUNDARY CHANGE
473 3,
474 7,1,1, .000123
475 8,2,1, .000123
476 9,3,1, .000123
477 THERMAL LOADS
478 1,
479 -39.3,1.250000
480
481 CONTINUE
482 BOUNDARY CHANGE

483 3,
 484 7,1,1, .000108
 485 8,2,1, .000108
 486 9,3,1, .000108
 487 THERMAL LOADS
 488 1,
 489 -34.5,1.250000
 490
 491 CONTINUE
 492 BOUNDARY CHANGE
 493 3,
 494 7,1,1, .000091
 495 8,2,1, .000091
 496 9,3,1, .000091
 497 THERMAL LOADS
 498 1,
 499 -29.1,1.250000
 500
 501 CONTINUE
 502 BOUNDARY CHANGE
 503 3,
 504 7,1,1, .000072
 505 8,2,1, .000072
 506 9,3,1, .000072
 507 THERMAL LOADS
 508 1,
 509 -23.1,1.250000
 510
 511 CONTINUE
 512 BOUNDARY CHANGE
 513 3,
 514 7,1,1, .000053
 515 8,2,1, .000053
 516 9,3,1, .000053
 517 THERMAL LOADS
 518 1,
 519 -16.8,1.250000
 520
 521 CONTINUE
 522 BOUNDARY CHANGE
 523 3,
 524 7,1,1, .000032
 525 8,2,1, .000032
 526 9,3,1, .000032
 527 THERMAL LOADS
 528 1,
 529 -10.2,1.250000
 530
 531 CONTINUE
 532 BOUNDARY CHANGE
 533 3,
 534 7,1,1, .000011
 535 8,2,1, .000011
 536 9,3,1, .000011
 537 THERMAL LOADS
 538 1,
 539 -3.4,1.250000
 540
 541 CONTINUE
 542 BOUNDARY CHANGE
 543 3,
 544 7,1,1, -.000011
 545 8,2,1, -.000011
 546 9,3,1, -.000011
 547 THERMAL LOADS
 548 1,
 549 3.4,1.250000
 550
 551 CONTINUE
 552 BOUNDARY CHANGE
 553 3,
 554 7,1,1, -.000032
 555 8,2,1, -.000032

556 9,3,1, -.000032
 557 THERMAL LOADS
 558 1,
 559 10.2,1.250000
 560
 561 CONTINUE
 562 BOUNDARY CHANGE
 563 3,
 564 7,1,1, -.000053
 565 8,2,1, -.000053
 566 9,3,1, -.000053
 567 THERMAL LOADS
 568 1,
 569 16.8,1.250000
 570
 571 CONTINUE
 572 BOUNDARY CHANGE
 573 3,
 574 7,1,1, -.000072
 575 8,2,1, -.000072
 576 9,3,1, -.000072
 577 THERMAL LOADS
 578 1,
 579 23.1,1.250000
 580
 581 CONTINUE
 582 BOUNDARY CHANGE
 583 3,
 584 7,1,1, -.000091
 585 8,2,1, -.000091
 586 9,3,1, -.000091
 587 THERMAL LOADS
 588 1,
 589 29.1,1.250000
 590
 591 CONTINUE
 592 BOUNDARY CHANGE
 593 3,
 594 7,1,1, -.000108
 595 8,2,1, -.000108
 596 9,3,1, -.000108
 597 THERMAL LOADS
 598 1,
 599 34.5,1.250000
 600
 601 CONTINUE
 602 BOUNDARY CHANGE
 603 3,
 604 7,1,1, -.000123
 605 8,2,1, -.000123
 606 9,3,1, -.000123
 607 THERMAL LOADS
 608 1,
 609 39.3,1.250000
 610
 611 CONTINUE
 612 BOUNDARY CHANGE
 613 3,
 614 7,1,1, -.000136
 615 8,2,1, -.000136
 616 9,3,1, -.000136
 617 THERMAL LOADS
 618 1,
 619 43.5,1.250000
 620
 621 CONTINUE
 622 BOUNDARY CHANGE
 623 3,
 624 7,1,1, -.000147
 625 8,2,1, -.000147
 626 9,3,1, -.000147
 627 THERMAL LOADS
 628 1,

629 46.9,1.250000
 630
 631 CONTINUE
 632 BOUNDARY CHANGE
 633 3,
 634 7,1,1, -.000155
 635 8,2,1, -.000155
 636 9,3,1, -.000155
 637 THERMAL LOADS
 638 1
 639 49.5,1.250000
 640
 641 CONTINUE
 642 BOUNDARY CHANGE
 643 3,
 644 7,1,1, -.000160
 645 8,2,1, -.000160
 646 9,3,1, -.000160
 647 THERMAL LOADS
 648 1
 649 51.3,1.250000
 650
 651 CONTINUE
 652 BOUNDARY CHANGE
 653 3,
 654 7,1,1, -.000163
 655 8,2,1, -.000163
 656 9,3,1, -.000163
 657 THERMAL LOADS
 658 1
 659 52.2,1.250000
 660
 661 CONTINUE
 662 BOUNDARY CHANGE
 663 3,
 664 7,1,1, -.000163
 665 8,2,1, -.000163
 666 9,3,1, -.000163
 667 THERMAL LOADS
 668 1
 669 52.2,1.250000
 670
 671 CONTINUE
 672 BOUNDARY CHANGE
 673 3,
 674 7,1,1, -.000160
 675 8,2,1, -.000160
 676 9,3,1, -.000160
 677 THERMAL LOADS
 678 1
 679 51.3,1.250000
 680
 681 CONTINUE
 682 BOUNDARY CHANGE
 683 3,
 684 7,1,1, -.000155
 685 8,2,1, -.000155
 686 9,3,1, -.000155
 687 THERMAL LOADS
 688 1
 689 49.5,1.250000
 690
 691 CONTINUE
 692 BOUNDARY CHANGE
 693 3,
 694 7,1,1, -.000147
 695 8,2,1, -.000147
 696 9,3,1, -.000147
 697 THERMAL LOADS
 698 1
 699 46.9,1.250000
 700

701 CONTINUE
 702 BOUNDARY CHANGE
 703 3,
 704 7,1,1, -.000136
 705 8,2,1, -.000136
 706 9,3,1, -.000136
 707 THERMAL LOADS
 708 1
 709 43.5,1.250000
 710
 711 CONTINUE
 712 BOUNDARY CHANGE
 713 3,
 714 7,1,1, -.000123
 715 8,2,1, -.000123
 716 9,3,1, -.000123
 717 THERMAL LOADS
 718 1
 719 39.3,1.250000
 720
 721 CONTINUE
 722 BOUNDARY CHANGE
 723 3,
 724 7,1,1, -.000108
 725 8,2,1, -.000108
 726 9,3,1, -.000108
 727 THERMAL LOADS
 728 1
 729 34.5,1.250000
 730
 731 CONTINUE
 732 BOUNDARY CHANGE
 733 3,
 734 7,1,1, -.000091
 735 8,2,1, -.000091
 736 9,3,1, -.000091
 737 THERMAL LOADS
 738 1
 739 29.1,1.250000
 740
 741 CONTINUE
 742 BOUNDARY CHANGE
 743 3,
 744 7,1,1, -.000072
 745 8,2,1, -.000072
 746 9,3,1, -.000072
 747 THERMAL LOADS
 748 1
 749 23.1,1.250000
 750
 751 CONTINUE
 752 BOUNDARY CHANGE
 753 3,
 754 7,1,1, -.000053
 755 8,2,1, -.000053
 756 9,3,1, -.000053
 757 THERMAL LOADS
 758 1
 759 16.8,1.250000
 760
 761 CONTINUE
 762 BOUNDARY CHANGE
 763 3,
 764 7,1,1, -.000032
 765 8,2,1, -.000032
 766 9,3,1, -.000032
 767 THERMAL LOADS
 768 1
 769 10.2,1.250000
 770
 771 CONTINUE
 772 BOUNDARY CHANGE
 773 3,

774 7,1,1, -.000011
 775 8,2,1, -.000011
 776 9,3,1, -.000011
 777 THERMAL LOADS
 778 1,
 779 3.4,1.250000
 780
 781 CONTINUE
 782 BOUNDARY CHANGE
 783 3,
 784 7,1,1, .000011
 785 8,2,1, .000011
 786 9,3,1, .000011
 787 THERMAL LOADS
 788 1,
 789 -3.4,1.250000
 790
 791 CONTINUE
 792 BOUNDARY CHANGE
 793 3,
 794 7,1,1, .000032
 795 8,2,1, .000032
 796 9,3,1, .000032
 797 THERMAL LOADS
 798 1,
 799 -10.2,1.250000
 800
 801 CONTINUE
 802 BOUNDARY CHANGE
 803 3,
 804 7,1,1, .000053
 805 8,2,1, .000053
 806 9,3,1, .000053
 807 THERMAL LOADS
 808 1,
 809 -16.8,1.250000
 810
 811 CONTINUE
 812 BOUNDARY CHANGE
 813 3,
 814 7,1,1, .000072
 815 8,2,1, .000072
 816 9,3,1, .000072
 817 THERMAL LOADS
 818 1,
 819 -23.1,1.250000
 820
 821 CONTINUE
 822 BOUNDARY CHANGE
 823 3,
 824 7,1,1, .000091
 825 8,2,1, .000091
 826 9,3,1, .000091
 827 THERMAL LOADS
 828 1,
 829 -29.1,1.250000
 830
 831 CONTINUE
 832 BOUNDARY CHANGE
 833 3,
 834 7,1,1, .000108
 835 8,2,1, .000108
 836 9,3,1, .000108
 837 THERMAL LOADS
 838 1,
 839 -34.5,1.250000
 840
 841 CONTINUE
 842 BOUNDARY CHANGE
 843 3,
 844 7,1,1, .000123
 845 8,2,1, .000123

846 9,3,1, .000123
 847 THERMAL LOADS
 848 1,
 849 -39.3,1.250000
 850
 851 CONTINUE
 852 BOUNDARY CHANGE
 853 3,
 854 7,1,1, .000136
 855 8,2,1, .000136
 856 9,3,1, .000136
 857 THERMAL LOADS
 858 1,
 859 -43.5,1.250000
 860
 861 CONTINUE
 862 BOUNDARY CHANGE
 863 3,
 864 7,1,1, .000147
 865 8,2,1, .000147
 866 9,3,1, .000147
 867 THERMAL LOADS
 868 1,
 869 -46.9,1.250000
 870
 871 CONTINUE
 872 BOUNDARY CHANGE
 873 3,
 874 7,1,1, .000155
 875 8,2,1, .000155
 876 9,3,1, .000155
 877 THERMAL LOADS
 878 1,
 879 -49.5,1.250000
 880
 881 CONTINUE
 882 BOUNDARY CHANGE
 883 3,
 884 7,1,1, .000160
 885 8,2,1, .000160
 886 9,3,1, .000160
 887 THERMAL LOADS
 888 1,
 889 -51.3,1.250000
 890
 891 CONTINUE
 892 BOUNDARY CHANGE
 893 3,
 894 7,1,1, .000163
 895 8,2,1, .000163
 896 9,3,1, .000163
 897 THERMAL LOADS
 898 1,
 899 -52.2,1.250000
 900
 901 CONTINUE
 902 BOUNDARY CHANGE
 903 3,
 904 7,1,1, .000163
 905 8,2,1, .000163
 906 9,3,1, .000163
 907 THERMAL LOADS
 908 1,
 909 -52.2,1.250000
 910
 911 CONTINUE
 912 BOUNDARY CHANGE
 913 3,
 914 7,1,1, .000160
 915 8,2,1, .000160
 916 9,3,1, .000160
 917 THERMAL LOADS

918 1
 919 -51.3,1.250000
 920
 921 CONTINUE
 922 BOUNDARY CHANGE
 923 3,
 924 7,1,1, .000155
 925 8,2,1, .000155
 926 9,3,1, .000155
 927 THERMAL LOADS
 928 1
 929 -49.5,1.250000
 930
 931 CONTINUE
 932 BOUNDARY CHANGE
 933 3,
 934 7,1,1, .000147
 935 8,2,1, .000147
 936 9,3,1, .000147
 937 THERMAL LOADS
 938 1
 939 -46.9,1.250000
 940
 941 CONTINUE
 942 BOUNDARY CHANGE
 943 3,
 944 7,1,1, .000136
 945 8,2,1, .000136
 946 9,3,1, .000136
 947 THERMAL LOADS
 948 1
 949 -43.5,1.250000
 950
 951 CONTINUE
 952 BOUNDARY CHANGE
 953 3,
 954 7,1,1, .000123
 955 8,2,1, .000123
 956 9,3,1, .000123
 957 THERMAL LOADS
 958 1
 959 -39.3,1.250000
 960
 961 CONTINUE
 962 BOUNDARY CHANGE
 963 3,
 964 7,1,1, .000108
 965 8,2,1, .000108
 966 9,3,1, .000108
 967 THERMAL LOADS
 968 1
 969 -34.5,1.250000
 970
 971 CONTINUE
 972 BOUNDARY CHANGE
 973 3,
 974 7,1,1, .000091
 975 8,2,1, .000091
 976 9,3,1, .000091
 977 THERMAL LOADS
 978 1
 979 -29.1,1.250000
 980
 981 CONTINUE
 982 BOUNDARY CHANGE
 983 3,
 984 7,1,1, .000072
 985 8,2,1, .000072
 986 9,3,1, .000072
 987 THERMAL LOADS
 988 1
 989 -23.1,1.250000

990
 991 CONTINUE
 992 BOUNDARY CHANGE
 993 3,
 994 7,1,1, .000053
 995 8,2,1, .000053
 996 9,3,1, .000053
 997 THERMAL LOADS
 998 1
 999 -16.8,1.250000
 1000
 1001 CONTINUE
 1002 BOUNDARY CHANGE
 1003 3,
 1004 7,1,1, .000032
 1005 8,2,1, .000032
 1006 9,3,1, .000032
 1007 THERMAL LOADS
 1008 1
 1009 -10.2,1.250000
 1010
 1011 CONTINUE
 1012 BOUNDARY CHANGE
 1013 3,
 1014 7,1,1, .000011
 1015 8,2,1, .000011
 1016 9,3,1, .000011
 1017 THERMAL LOADS
 1018 1
 1019 -3.4,1.250000
 1020
 1021 CONTINUE

APPENDIX 7. DATA INPUT FOR OPEN SYMMETRIC TMF LOOP

```

1  TITLE          THERMOMECHANICAL LOOP NO. 2 WITH FUNCTIONAL THEORY
2  SIZING          15000      4      9      9      2      10
3  POST            2
4  ALL POINTS
5  INPUT TAPE      1
6  HYPOELAS
7  STATE VARS      16
8  NO LOADCOR      1
9  RESTART
10 END
11 MESH2D
12 BLOCKS
13      1      4      10      1      1      9              6
14 DEFINE
15      1      2      2      1      2      3      4
16 BOUNDARY
17      1              1.
18      2              1.      1.
19      3              0.      1.
20      4
21 CONSTRAINT
22      2
23      1      3      1
24      1      4      2
25 MERGE
26 .0005
27 GENERATE
28 CONNECTIVITY
29      1
30 COORDINATES
31      1
32 BOUNDARY CONDITIONS
33      0      1      1
34 BOUNDARY CONDITIONS
35 1,
36 1,3,1,1,1.E-8
37 THERMAL LOADS
38 1,
39 0.,1.E-8
40
41 PROPERTY
42      1
43      26.0E6      .322      0.E-5
44      1      4
45 POST
46      2      16      16
47      1
48      11
49 PRINT CHOICE
50      1

```

51	1	104	7,1,1, -.000126
52	CONTROL	105	8,2,1, -.000126
53	49,15,1,0	106	9,3,1, -.000126
54	.05	107	THERMAL LOADS
55	RESTART	108	1,
56	1,1,0,8,8	109	41.1,1.250000
57	INITIAL STATE	110	
58	1,1,1	111	CONTINUE
59	1,4,1,4	112	BOUNDARY CHANGE
60	820.	113	3,
61	END OPTION	114	7,1,1, -.000142
62	BOUNDARY CHANGE	115	8,2,1, -.000142
63	3,	116	9,3,1, -.000142
64	7,1,1, .000150	117	THERMAL LOADS
65	8,2,1, .000150	118	1,
66	9,3,1, .000150	119	45.0,1.250000
67	THERMAL LOADS	120	
68	1,	121	CONTINUE
69	19.0,1.250000	122	BOUNDARY CHANGE
70		123	3,
71	CONTINUE	124	7,1,1, -.000155
72	BOUNDARY CHANGE	125	8,2,1, -.000155
73	3,	126	9,3,1, -.000155
74	7,1,1, -.000065	127	THERMAL LOADS
75	8,2,1, -.000065	128	1,
76	9,3,1, -.000065	129	48.1,1.250000
77	THERMAL LOADS	130	
78	1,	131	CONTINUE
79	25.6,1.250000	132	BOUNDARY CHANGE
80		133	3,
81	CONTINUE	134	7,1,1, -.000166
82	BOUNDARY CHANGE	135	8,2,1, -.000166
83	3,	136	9,3,1, -.000166
84	7,1,1, -.000088	137	THERMAL LOADS
85	8,2,1, -.000088	138	1,
86	9,3,1, -.000088	139	50.4,1.250000
87	THERMAL LOADS	140	
88	1,	141	CONTINUE
89	31.3,1.250000	142	BOUNDARY CHANGE
90		143	3,
91	CONTINUE	144	7,1,1, -.000174
92	BOUNDARY CHANGE	145	8,2,1, -.000174
93	3,	146	9,3,1, -.000174
94	7,1,1, -.000108	147	THERMAL LOADS
95	8,2,1, -.000108	148	1,
96	9,3,1, -.000108	149	51.8,1.250000
97	THERMAL LOADS	150	
98	1,	151	CONTINUE
99	36.5,1.250000	152	BOUNDARY CHANGE
100		153	3,
101	CONTINUE	154	7,1,1, -.000179
102	BOUNDARY CHANGE	155	8,2,1, -.000179
103	3,	156	9,3,1, -.000179

157	THERMAL LOADS	210	
158	1,	211	CONTINUE
159	52.3,1.250000	212	BOUNDARY CHANGE
160		213	3,
161	CONTINUE	214	7,1,1, -.000031
162	BOUNDARY CHANGE	215	8,2,1, -.000031
163	3,	216	9,3,1, -.000031
164	7,1,1, -.000180	217	THERMAL LOADS
165	8,2,1, -.000180	218	1,
166	9,3,1, -.000180	219	37.5,1.250000
167	THERMAL LOADS	220	
168	1,	221	CONTINUE
169	52.0,1.250000	222	BOUNDARY CHANGE
170		223	3,
171	CONTINUE	224	7,1,1, -.000028
172	BOUNDARY CHANGE	225	8,2,1, -.000028
173	3,	226	9,3,1, -.000028
174	7,1,1, -.000179	227	THERMAL LOADS
175	8,2,1, -.000179	228	1,
176	9,3,1, -.000179	229	32.4,1.250000
177	THERMAL LOADS	230	
178	1,	231	CONTINUE
179	50.7,1.250000	232	BOUNDARY CHANGE
180		233	3,
181	CONTINUE	234	7,1,1, -.000024
182	BOUNDARY CHANGE	235	8,2,1, -.000024
183	3,	236	9,3,1, -.000024
184	7,1,1, -.000175	237	THERMAL LOADS
185	8,2,1, -.000175	238	1,
186	9,3,1, -.000175	239	26.8,1.250000
187	THERMAL LOADS	240	
188	1,	241	CONTINUE
189	48.6,1.250000	242	BOUNDARY CHANGE
190		243	3,
191	CONTINUE	244	7,1,1, -.000020
192	BOUNDARY CHANGE	245	8,2,1, -.000020
193	3,	246	9,3,1, -.000020
194	7,1,1, -.000243	247	THERMAL LOADS
195	8,2,1, -.000243	248	1,
196	9,3,1, -.000243	249	20.7,1.250000
197	THERMAL LOADS	250	
198	1,	251	CONTINUE
199	45.7,1.250000	252	BOUNDARY CHANGE
200		253	3,
201	CONTINUE	254	7,1,1, -.000015
202	BOUNDARY CHANGE	255	8,2,1, -.000015
203	3,	256	9,3,1, -.000015
204	7,1,1, -.000034	257	THERMAL LOADS
205	8,2,1, -.000034	258	1,
206	9,3,1, -.000034	259	14.2,1.250000
207	THERMAL LOADS	260	
208	1,	261	CONTINUE
209	41.9,1.250000	262	BOUNDARY CHANGE

263	3,	316	9,3,1, .000086
264	7,1,1, -.000011	317	THERMAL LOADS
265	8,2,1, -.000011	318	1,
266	9,3,1, -.000011	319	-25.6,1.250000
267	THERMAL LOADS	320	
268	1,	321	CONTINUE
269	7.5,1.250000	322	BOUNDARY CHANGE
270		323	3,
271	CONTINUE	324	7,1,1, .000114
272	BOUNDARY CHANGE	325	8,2,1, .000114
273	3,	326	9,3,1, .000114
274	7,1,1, .000108	327	THERMAL LOADS
275	8,2,1, .000108	328	1,
276	9,3,1, .000108	329	-31.3,1.250000
277	THERMAL LOADS	330	
278	1,	331	CONTINUE
279	.7,1.250000	332	BOUNDARY CHANGE
280		333	3,
281	CONTINUE	334	7,1,1, .000139
282	BOUNDARY CHANGE	335	8,2,1, .000139
283	3,	336	9,3,1, .000139
284	7,1,1, -.000063	337	THERMAL LOADS
285	8,2,1, -.000063	338	1,
286	9,3,1, -.000063	339	-36.5,1.250000
287	THERMAL LOADS	340	
288	1,	341	CONTINUE
289	-6.1,1.250000	342	BOUNDARY CHANGE
290		343	3,
291	CONTINUE	344	7,1,1, .000162
292	BOUNDARY CHANGE	345	8,2,1, .000162
293	3,	346	9,3,1, .000162
294	7,1,1, .000569	347	THERMAL LOADS
295	8,2,1, .000569	348	1,
296	9,3,1, .000569	349	-41.1,1.250000
297	THERMAL LOADS	350	
298	1,	351	CONTINUE
299	-12.9,1.250000	352	BOUNDARY CHANGE
300		353	3,
301	CONTINUE	354	7,1,1, .000183
302	BOUNDARY CHANGE	355	8,2,1, .000183
303	3,	356	9,3,1, .000183
304	7,1,1, .001229	357	THERMAL LOADS
305	8,2,1, .001229	358	1,
306	9,3,1, .001229	359	-45.0,1.250000
307	THERMAL LOADS	360	
308	1,	361	CONTINUE
309	-19.4,1.250000	362	BOUNDARY CHANGE
310		363	3,
311	CONTINUE	364	7,1,1, .000200
312	BOUNDARY CHANGE	365	8,2,1, .000200
313	3,	366	9,3,1, .000200
314	7,1,1, .000086	367	THERMAL LOADS
315	8,2,1, .000086	368	1,

369 -48.1,1.250000
 370
 371 CONTINUE
 372 BOUNDARY CHANGE
 373 3,
 374 7,1,1, .000214
 375 8,2,1, .000214
 376 9,3,1, .000214
 377 THERMAL LOADS
 378 1,
 379 -50.4,1.250000
 380
 381 CONTINUE
 382 BOUNDARY CHANGE
 383 3,
 384 7,1,1, .000224
 385 8,2,1, .000224
 386 9,3,1, .000224
 387 THERMAL LOADS
 388 1,
 389 -51.8,1.250000
 390
 391 CONTINUE
 392 BOUNDARY CHANGE
 393 3,
 394 7,1,1, .000230
 395 8,2,1, .000230
 396 9,3,1, .000230
 397 THERMAL LOADS
 398 1,
 399 -52.3,1.250000
 400
 401 CONTINUE
 402 BOUNDARY CHANGE
 403 3,
 404 7,1,1, .000247
 405 8,2,1, .000247
 406 9,3,1, .000247
 407 THERMAL LOADS
 408 1,
 409 -52.0,1.250000
 410
 411 CONTINUE
 412 BOUNDARY CHANGE
 413 3,
 414 7,1,1, .000048
 415 8,2,1, .000048
 416 9,3,1, .000048
 417 THERMAL LOADS
 418 1,
 419 -50.7,1.250000
 420
 421 CONTINUE

422 BOUNDARY CHANGE
 423 3,
 424 7,1,1, .000047
 425 8,2,1, .000047
 426 9,3,1, .000047
 427 THERMAL LOADS
 428 1,
 429 -48.6,1.250000
 430
 431 CONTINUE
 432 BOUNDARY CHANGE
 433 3,
 434 7,1,1, .000045
 435 8,2,1, .000045
 436 9,3,1, .000045
 437 THERMAL LOADS
 438 1,
 439 -45.7,1.250000
 440
 441 CONTINUE
 442 BOUNDARY CHANGE
 443 3,
 444 7,1,1, .000043
 445 8,2,1, .000043
 446 9,3,1, .000043
 447 THERMAL LOADS
 448 1,
 449 -41.9,1.250000
 450
 451 CONTINUE
 452 BOUNDARY CHANGE
 453 3,
 454 7,1,1, .000039
 455 8,2,1, .000039
 456 9,3,1, .000039
 457 THERMAL LOADS
 458 1,
 459 -37.5,1.250000
 460
 461 CONTINUE
 462 BOUNDARY CHANGE
 463 3,
 464 7,1,1, .000035
 465 8,2,1, .000035
 466 9,3,1, .000035
 467 THERMAL LOADS
 468 1,
 469 -32.4,1.250000
 470
 471 CONTINUE
 472 BOUNDARY CHANGE
 473 3,
 474 7,1,1, .000030

475 8,2,1, .000030
 476 9,3,1, .000030
 477 THERMAL LOADS
 478 1,
 479 -26.8,1.250000
 480
 481 CONTINUE
 482 BOUNDARY CHANGE
 483 3,
 484 7,1,1, .000025
 485 8,2,1, .000025
 486 9,3,1, .000025
 487 THERMAL LOADS
 488 1,
 489 -20.7,1.250000
 490
 491 CONTINUE
 492 BOUNDARY CHANGE
 493 3,
 494 7,1,1, .000019
 495 8,2,1, .000019
 496 9,3,1, .000019
 497 THERMAL LOADS
 498 1,
 499 -14.2,1.250000
 500
 501 CONTINUE
 502 BOUNDARY CHANGE
 503 3,
 504 7,1,1, .000013
 505 8,2,1, .000013
 506 9,3,1, .000013
 507 THERMAL LOADS
 508 1,
 509 -7.5,1.250000
 510
 511 CONTINUE
 512 BOUNDARY CHANGE
 513 3,
 514 7,1,1, -.000106
 515 8,2,1, -.000106
 516 9,3,1, -.000106
 517 THERMAL LOADS
 518 1,
 519 -.7,1.250000
 520
 521 CONTINUE
 522 BOUNDARY CHANGE
 523 3,
 524 7,1,1, .000063
 525 8,2,1, .000063
 526 9,3,1, .000063
 527 THERMAL LOADS
 528 1,
 529 6.1,1.250000
 530

531 CONTINUE
 532 BOUNDARY CHANGE
 533 3,
 534 7,1,1, -.000569
 535 8,2,1, -.000569
 536 9,3,1, -.000569
 537 THERMAL LOADS
 538 1,
 539 12.9,1.250000
 540
 541 CONTINUE
 542 BOUNDARY CHANGE
 543 3,
 544 7,1,1, -.001229
 545 8,2,1, -.001229
 546 9,3,1, -.001229
 547 THERMAL LOADS
 548 1,
 549 19.4,1.250000
 550
 551 CONTINUE
 552 BOUNDARY CHANGE
 553 3,
 554 7,1,1, -.000067
 555 8,2,1, -.000067
 556 9,3,1, -.000067
 557 THERMAL LOADS
 558 1,
 559 25.6,1.250000
 560
 561 CONTINUE
 562 BOUNDARY CHANGE
 563 3,
 564 7,1,1, -.000088
 565 8,2,1, -.000088
 566 9,3,1, -.000088
 567 THERMAL LOADS
 568 1,
 569 31.3,1.250000
 570
 571 CONTINUE
 572 BOUNDARY CHANGE
 573 3,
 574 7,1,1, -.000108
 575 8,2,1, -.000108
 576 9,3,1, -.000108
 577 THERMAL LOADS
 578 1,
 579 36.5,1.250000
 580
 581 CONTINUE
 582 BOUNDARY CHANGE
 583 3,
 584 7,1,1, -.000126
 585 8,2,1, -.000126
 586 9,3,1, -.000126

587 THERMAL LOADS
 588 1,
 589 41.1,1.250000
 590
 591 CONTINUE
 592 BOUNDARY CHANGE
 593 3,
 594 7,1,1, -.000142
 595 8,2,1, -.000142
 596 9,3,1, -.000142
 597 THERMAL LOADS
 598 1,
 599 45.0,1.250000
 600
 601 CONTINUE
 602 BOUNDARY CHANGE
 603 3,
 604 7,1,1, -.000155
 605 8,2,1, -.000155
 606 9,3,1, -.000155
 607 THERMAL LOADS
 608 1,
 609 48.1,1.250000
 610
 611 CONTINUE
 612 BOUNDARY CHANGE
 613 3,
 614 7,1,1, -.000166
 615 8,2,1, -.000166
 616 9,3,1, -.000166
 617 THERMAL LOADS
 618 1,
 619 50.4,1.250000
 620
 621 CONTINUE
 622 BOUNDARY CHANGE
 623 3,
 624 7,1,1, -.000174
 625 8,2,1, -.000174
 626 9,3,1, -.000174
 627 THERMAL LOADS
 628 1,
 629 51.8,1.250000
 630
 631 CONTINUE
 632 BOUNDARY CHANGE
 633 3,
 634 7,1,1, -.000179
 635 8,2,1, -.000179
 636 9,3,1, -.000179
 637 THERMAL LOADS
 638 1,
 639 52.3,1.250000
 640

641 CONTINUE
 642 BOUNDARY CHANGE
 643 3,
 644 7,1,1, -.000180
 645 8,2,1, -.000180
 646 9,3,1, -.000180
 647 THERMAL LOADS
 648 1,
 649 52.0,1.250000
 650
 651 CONTINUE
 652 BOUNDARY CHANGE
 653 3,
 654 7,1,1, -.000179
 655 8,2,1, -.000179
 656 9,3,1, -.000179
 657 THERMAL LOADS
 658 1,
 659 50.7,1.250000
 660
 661 CONTINUE
 662 BOUNDARY CHANGE
 663 3,
 664 7,1,1, -.000175
 665 8,2,1, -.000175
 666 9,3,1, -.000175
 667 THERMAL LOADS
 668 1,
 669 48.6,1.250000
 670
 671 CONTINUE
 672 BOUNDARY CHANGE
 673 3,
 674 7,1,1, -.000243
 675 8,2,1, -.000243
 676 9,3,1, -.000243
 677 THERMAL LOADS
 678 1,
 679 45.7,1.250000
 680
 681 CONTINUE
 682 BOUNDARY CHANGE
 683 3,
 684 7,1,1, -.000034
 685 8,2,1, -.000034
 686 9,3,1, -.000034
 687 THERMAL LOADS
 688 1,
 689 41.9,1.250000
 690
 691 CONTINUE
 692 BOUNDARY CHANGE
 693 3,
 694 7,1,1, -.000031

695 8,2,1, -.000031
 696 9,3,1, -.000031
 697 THERMAL LOADS
 698 1,
 699 37.5,1.250000
 700
 701 CONTINUE
 702 BOUNDARY CHANGE
 703 3,
 704 7,1,1, -.000028
 705 8,2,1, -.000028
 706 9,3,1, -.000028
 707 THERMAL LOADS
 708 1,
 709 32.4,1.250000
 710
 711 CONTINUE
 712 BOUNDARY CHANGE
 713 3,
 714 7,1,1, -.000024
 715 8,2,1, -.000024
 716 9,3,1, -.000024
 717 THERMAL LOADS
 718 1,
 719 26.8,1.250000
 720
 721 CONTINUE
 722 BOUNDARY CHANGE
 723 3,
 724 7,1,1, -.000020
 725 8,2,1, -.000020
 726 9,3,1, -.000020
 727 THERMAL LOADS
 728 1,
 729 20.7,1.250000
 730
 731 CONTINUE
 732 BOUNDARY CHANGE
 733 3,
 734 7,1,1, -.000015
 735 8,2,1, -.000015
 736 9,3,1, -.000015
 737 THERMAL LOADS
 738 1,
 739 14.2,1.250000
 740
 741 CONTINUE
 742 BOUNDARY CHANGE
 743 3,
 744 7,1,1, -.000011
 745 8,2,1, -.000011
 746 9,3,1, -.000011
 747 THERMAL LOADS
 748 1,

749 7.5,1.250000
 750
 751 CONTINUE
 752 BOUNDARY CHANGE
 753 3,
 754 7,1,1, .000108
 755 8,2,1, .000108
 756 9,3,1, .000108
 757 THERMAL LOADS
 758 1,
 759 .7,1.250000
 760
 761 CONTINUE
 762 BOUNDARY CHANGE
 763 3,
 764 7,1,1, -.000063
 765 8,2,1, -.000063
 766 9,3,1, -.000063
 767 THERMAL LOADS
 768 1,
 769 -6.1,1.250000
 770
 771 CONTINUE
 772 BOUNDARY CHANGE
 773 3,
 774 7,1,1, .000569
 775 8,2,1, .000569
 776 9,3,1, .000569
 777 THERMAL LOADS
 778 1,
 779 -12.9,1.250000
 780
 781 CONTINUE
 782 BOUNDARY CHANGE
 783 3,
 784 7,1,1, .001229
 785 8,2,1, .001229
 786 9,3,1, .001229
 787 THERMAL LOADS
 788 1,
 789 -19.4,1.250000
 790
 791 CONTINUE
 792 BOUNDARY CHANGE
 793 3,
 794 7,1,1, .000086
 795 8,2,1, .000086
 796 9,3,1, .000086
 797 THERMAL LOADS
 798 1,
 799 -25.6,1.250000
 800
 801 CONTINUE
 802 BOUNDARY CHANGE

803 3,
 804 7,1,1, .000114
 805 8,2,1, .000114
 806 9,3,1, .000114
 807 THERMAL LOADS
 808 1,
 809 -31.3,1.250000
 810
 811 CONTINUE
 812 BOUNDARY CHANGE
 813 3,
 814 7,1,1, .000139
 815 8,2,1, .000139
 816 9,3,1, .000139
 817 THERMAL LOADS
 818 1,
 819 -36.5,1.250000
 820
 821 CONTINUE
 822 BOUNDARY CHANGE
 823 3,
 824 7,1,1, .000162
 825 8,2,1, .000162
 826 9,3,1, .000162
 827 THERMAL LOADS
 828 1,
 829 -41.1,1.250000
 830
 831 CONTINUE
 832 BOUNDARY CHANGE
 833 3,
 834 7,1,1, .000183
 835 8,2,1, .000183
 836 9,3,1, .000183
 837 THERMAL LOADS
 838 1,
 839 -45.0,1.250000
 840
 841 CONTINUE
 842 BOUNDARY CHANGE
 843 3,
 844 7,1,1, .000200
 845 8,2,1, .000200
 846 9,3,1, .000200
 847 THERMAL LOADS
 848 1,
 849 -48.1,1.250000
 850
 851 CONTINUE
 852 BOUNDARY CHANGE
 853 3,
 854 7,1,1, .000214
 855 8,2,1, .000214
 856 9,3,1, .000214

857 THERMAL LOADS
 858 1,
 859 -50.4,1.250000
 860
 861 CONTINUE
 862 BOUNDARY CHANGE
 863 3,
 864 7,1,1, .000224
 865 8,2,1, .000224
 866 9,3,1, .000224
 867 THERMAL LOADS
 868 1,
 869 -51.8,1.250000
 870
 871 CONTINUE
 872 BOUNDARY CHANGE
 873 3,
 874 7,1,1, .000230
 875 8,2,1, .000230
 876 9,3,1, .000230
 877 THERMAL LOADS
 878 1,
 879 -52.3,1.250000
 880
 881 CONTINUE
 882 BOUNDARY CHANGE
 883 3,
 884 7,1,1, .000247
 885 8,2,1, .000247
 886 9,3,1, .000247
 887 THERMAL LOADS
 888 1,
 889 -52.0,1.250000
 890
 891 CONTINUE
 892 BOUNDARY CHANGE
 893 3,
 894 7,1,1, .000048
 895 8,2,1, .000048
 896 9,3,1, .000048
 897 THERMAL LOADS
 898 1,
 899 -50.7,1.250000
 900
 901 CONTINUE
 902 BOUNDARY CHANGE
 903 3,
 904 7,1,1, .000047
 905 8,2,1, .000047
 906 9,3,1, .000047
 907 THERMAL LOADS
 908 1,
 909 -48.6,1.250000
 910

911 CONTINUE
 912 BOUNDARY CHANGE
 913 3,
 914 7,1,1, .000045
 915 8,2,1, .000045
 916 9,3,1, .000045
 917 THERMAL LOADS
 918 1,
 919 -45.7,1.250000
 920
 921 CONTINUE
 922 BOUNDARY CHANGE
 923 3,
 924 7,1,1, .000043
 925 8,2,1, .000043
 926 9,3,1, .000043
 927 THERMAL LOADS
 928 1,
 929 -41.9,1.250000
 930
 931 CONTINUE
 932 BOUNDARY CHANGE
 933 3,
 934 7,1,1, .000039
 935 8,2,1, .000039
 936 9,3,1, .000039
 937 THERMAL LOADS
 938 1,
 939 -37.5,1.250000
 940
 941 CONTINUE
 942 BOUNDARY CHANGE
 943 3,
 944 7,1,1, .000035
 945 8,2,1, .000035
 946 9,3,1, .000035
 947 THERMAL LOADS
 948 1,
 949 -32.4,1.250000
 950
 951 CONTINUE
 952 BOUNDARY CHANGE
 953 3,
 954 7,1,1, .000030
 955 8,2,1, .000030
 956 9,3,1, .000030
 957 THERMAL LOADS
 958 1,
 959 -26.8,1.250000
 960
 961 CONTINUE
 962 BOUNDARY CHANGE
 963 3,
 964 7,1,1, .000025
 965 8,2,1, .000025

966 9,3,1, .000025
 967 THERMAL LOADS
 968 1,
 969 -20.7,1.250000
 970
 971 CONTINUE
 972 BOUNDARY CHANGE
 973 3,
 974 7,1,1, .000019
 975 8,2,1, .000019
 976 9,3,1, .000019
 977 THERMAL LOADS
 978 1,
 979 -14.2,1.250000
 980
 981 CONTINUE
 982 BOUNDARY CHANGE
 983 3,
 984 7,1,1, .000013
 985 8,2,1, .000013
 986 9,3,1, .000013
 987 THERMAL LOADS
 988 1,
 989 -7.5,1.250000
 990
 991 CONTINUE
 992 BOUNDARY CHANGE
 993 3,
 994 7,1,1, -.000106
 995 8,2,1, -.000106
 996 9,3,1, -.000106
 997 THERMAL LOADS
 998 1,
 999 -.7,1.250000
 1000
 1001 CONTINUE
 1002 BOUNDARY CHANGE
 1003 3,
 1004 7,1,1, .000063
 1005 8,2,1, .000063
 1006 9,3,1, .000063
 1007 THERMAL LOADS
 1008 1,
 1009 6.1,1.250000
 1010
 1011 CONTINUE
 1012 BOUNDARY CHANGE
 1013 3,
 1014 7,1,1, -.000569
 1015 8,2,1, -.000569
 1016 9,3,1, -.000569
 1017 THERMAL LOADS
 1018 1,
 1019 12.9,1.250000
 1020
 1021 CONTINUE

APPENDIX 8. DATA INPUT FOR OPEN NONSYMMETRIC TMF LOOP

```

1  TITLE          THERMOMECHANICAL LOOP NO. 3 WITH FUNCTIONAL THEORY
2  SIZING          15000    4    9    9    2    10
3  POST            2
4  ALL POINTS
5  INPUT TAPE      1
6  HYPOELAS
7  STATE VARS      16
8  NO LOADCOR      1
9  RESTART
10 END
11 MESH2D
12 BLOCKS
13     1    4    10    1    1    9        6
14 DEFINE
15     1    2    2    1    2    3    4
16 BOUNDARY
17     1        1.
18     2        1.        1.
19     3        0.        1.
20     4
21 CONSTRAINT
22     2
23     1    3    1
24     1    4    2
25 MERGE
26 .0005
27 GENERATE
28 CONNECTIVITY
29     1
30 COORDINATES
31         1
32 BOUNDARY CONDITIONS
33     0    1    1
34 BOUNDARY CONDITIONS
35     1,
36     1,3,1,1,1.E-8
37 THERMAL LOADS
38     1,
39     0.,1.E-8
40
41 PROPERTY
42     1
43     26.0E6        .322        0.E-5
44     1    4
45 POST
46     2    16    16
47     1
48     11
49 PRINT CHOICE
50         1

```

51	1	104	7,1,1, -.000344
52	CONTROL	105	8,2,1, -.000344
53	49,15,1,0	106	9,3,1, -.000344
54	.05	107	THERMAL LOADS
55	RESTART	108	1,
56	1,1,0,8,8	109	68.9,2.104167
57	INITIAL STATE	110	
58	1,1,1	111	CONTINUE
59	1,4,1,4	112	BOUNDARY CHANGE
60	940.	113	3,
61	END OPTION	114	7,1,1, -.000378
62	BOUNDARY CHANGE	115	8,2,1, -.000378
63	3,	116	9,3,1, -.000378
64	7,1,1, .000000	117	THERMAL LOADS
65	8,2,1, .000000	118	1,
66	9,3,1, .000000	119	79.6,2.104167
67	THERMAL LOADS	120	
68	1,	121	CONTINUE
69	.0,2.104167	122	BOUNDARY CHANGE
70		123	3,
71	CONTINUE	124	7,1,1, -.000411
72	BOUNDARY CHANGE	125	8,2,1, -.000411
73	3,	126	9,3,1, -.000411
74	7,1,1, -.000085	127	THERMAL LOADS
75	8,2,1, -.000085	128	1,
76	9,3,1, -.000085	129	86.5,2.104167
77	THERMAL LOADS	130	
78	1,	131	CONTINUE
79	19.5,2.104167	132	BOUNDARY CHANGE
80		133	3,
81	CONTINUE	134	7,1,1, -.000424
82	BOUNDARY CHANGE	135	8,2,1, -.000424
83	3,	136	9,3,1, -.000424
84	7,1,1, -.000166	137	THERMAL LOADS
85	8,2,1, -.000166	138	1,
86	9,3,1, -.000166	139	89.2,2.104167
87	THERMAL LOADS	140	
88	1,	141	CONTINUE
89	38.1,2.104167	142	BOUNDARY CHANGE
90		143	3,
91	CONTINUE	144	7,1,1, -.000401
92	BOUNDARY CHANGE	145	8,2,1, -.000401
93	3,	146	9,3,1, -.000401
94	7,1,1, -.000274	147	THERMAL LOADS
95	8,2,1, -.000274	148	1,
96	9,3,1, -.000274	149	87.6,2.104167
97	THERMAL LOADS	150	
98	1,	151	CONTINUE
99	54.8,2.104167	152	BOUNDARY CHANGE
100		153	3,
101	CONTINUE	154	7,1,1, -.000374
102	BOUNDARY CHANGE	155	8,2,1, -.000374
103	3,	156	9,3,1, -.000374
		157	THERMAL LOADS

158 1,
 159 81.8,2.104167
 160
 161 CONTINUE
 162 BOUNDARY CHANGE
 163 3,
 164 7,1,1, -.000246
 165 8,2,1, -.000246
 166 9,3,1, -.000246
 167 THERMAL LOADS
 168 1,
 169 72.0,2.104167
 170
 171 CONTINUE
 172 BOUNDARY CHANGE
 173 3,
 174 7,1,1, -.000201
 175 8,2,1, -.000201
 176 9,3,1, -.000201
 177 THERMAL LOADS
 178 1,
 179 58.7,2.104167
 180
 181 CONTINUE
 182 BOUNDARY CHANGE
 183 3,
 184 7,1,1, -.000100
 185 8,2,1, -.000100
 186 9,3,1, -.000100
 187 THERMAL LOADS
 188 1,
 189 42.6,2.104167
 190
 191 CONTINUE
 192 BOUNDARY CHANGE
 193 3,
 194 7,1,1, .000146
 195 8,2,1, .000146
 196 9,3,1, .000146
 197 THERMAL LOADS
 198 1,
 199 24.4,2.104167
 200
 201 CONTINUE
 202 BOUNDARY CHANGE
 203 3,
 204 7,1,1, .000030
 205 8,2,1, .000030
 206 9,3,1, .000030
 207 THERMAL LOADS
 208 1,
 209 5.1,2.104167
 210

211 CONTINUE
 212 BOUNDARY CHANGE
 213 3,
 214 7,1,1, .000000
 215 8,2,1, .000000
 216 9,3,1, .000000
 217 THERMAL LOADS
 218 1,
 219 .0,2.104167
 220
 221 CONTINUE
 222 BOUNDARY CHANGE
 223 3,
 224 7,1,1, .000000
 225 8,2,1, .000000
 226 9,3,1, .000000
 227 THERMAL LOADS
 228 1,
 229 .0,2.104167
 230
 231 CONTINUE
 232 BOUNDARY CHANGE
 233 3,
 234 7,1,1, .000000
 235 8,2,1, .000000
 236 9,3,1, .000000
 237 THERMAL LOADS
 238 1,
 239 .0,2.104167
 240
 241 CONTINUE
 242 BOUNDARY CHANGE
 243 3,
 244 7,1,1, .000000
 245 8,2,1, .000000
 246 9,3,1, .000000
 247 THERMAL LOADS
 248 1,
 249 .0,2.104167
 250
 251 CONTINUE
 252 BOUNDARY CHANGE
 253 3,
 254 7,1,1, .000000
 255 8,2,1, .000000
 256 9,3,1, .000000
 257 THERMAL LOADS
 258 1,
 259 .0,2.104167
 260
 261 CONTINUE
 262 BOUNDARY CHANGE
 263 3,

264 7,1,1, .000000
 265 8,2,1, .000000
 266 9,3,1, .000000
 267 THERMAL LOADS
 268 1,
 269 .0,2.104167
 270
 271 CONTINUE
 272 BOUNDARY CHANGE
 273 3,
 274 7,1,1, .000000
 275 8,2,1, .000000
 276 9,3,1, .000000
 277 THERMAL LOADS
 278 1,
 279 .0,2.104167
 280
 281 CONTINUE
 282 BOUNDARY CHANGE
 283 3,
 284 7,1,1, .000000
 285 8,2,1, .000000
 286 9,3,1, .000000
 287 THERMAL LOADS
 288 1,
 289 .0,2.104167
 290
 291 CONTINUE
 292 BOUNDARY CHANGE
 293 3,
 294 7,1,1, .000000
 295 8,2,1, .000000
 296 9,3,1, .000000
 297 THERMAL LOADS
 298 1,
 299 .0,2.104167
 300
 301 CONTINUE
 302 BOUNDARY CHANGE
 303 3,
 304 7,1,1, .000000
 305 8,2,1, .000000
 306 9,3,1, .000000
 307 THERMAL LOADS
 308 1,
 309 .0,2.104167
 310
 311 CONTINUE
 312 BOUNDARY CHANGE
 313 3,
 314 7,1,1, .000000
 315 8,2,1, .000000
 316 9,3,1, .000000

317 THERMAL LOADS
 318 1,
 319 .0,2.104167
 320
 321 CONTINUE
 322 BOUNDARY CHANGE
 323 3,
 324 7,1,1, .000000
 325 8,2,1, .000000
 326 9,3,1, .000000
 327 THERMAL LOADS
 328 1,
 329 .0,2.104167
 330
 331 CONTINUE
 332 BOUNDARY CHANGE
 333 3,
 334 7,1,1, .000000
 335 8,2,1, .000000
 336 9,3,1, .000000
 337 THERMAL LOADS
 338 1,
 339 .0,2.104167
 340
 341 CONTINUE
 342 BOUNDARY CHANGE
 343 3,
 344 7,1,1, .000000
 345 8,2,1, .000000
 346 9,3,1, .000000
 347 THERMAL LOADS
 348 1,
 349 .0,2.104167
 350
 351 CONTINUE
 352 BOUNDARY CHANGE
 353 3,
 354 7,1,1, .000000
 355 8,2,1, .000000
 356 9,3,1, .000000
 357 THERMAL LOADS
 358 1,
 359 .0,2.104167
 360
 361 CONTINUE
 362 BOUNDARY CHANGE
 363 3,
 364 7,1,1, .000000
 365 8,2,1, .000000
 366 9,3,1, .000000
 367 THERMAL LOADS
 368 1,
 369 .0,2.104166

370
 371 CONTINUE
 372 BOUNDARY CHANGE
 373 3,
 374 7,1,1, .000000
 375 8,2,1, .000000
 376 9,3,1, .000000
 377 THERMAL LOADS
 378 1,
 379 .0,2.104167
 380
 381 CONTINUE
 382 BOUNDARY CHANGE
 383 3,
 384 7,1,1, .000000
 385 8,2,1, .000000
 386 9,3,1, .000000
 387 THERMAL LOADS
 388 1,
 389 .0,2.104167
 390
 391 CONTINUE
 392 BOUNDARY CHANGE
 393 3,
 394 7,1,1, .000000
 395 8,2,1, .000000
 396 9,3,1, .000000
 397 THERMAL LOADS
 398 1,
 399 .0,2.104166
 400
 401 CONTINUE
 402 BOUNDARY CHANGE
 403 3,
 404 7,1,1, .000027
 405 8,2,1, .000027
 406 9,3,1, .000027
 407 THERMAL LOADS
 408 1,
 409 -5.1,2.104167
 410
 411 CONTINUE
 412 BOUNDARY CHANGE
 413 3,
 414 7,1,1, .000131
 415 8,2,1, .000131
 416 9,3,1, .000131
 417 THERMAL LOADS
 418 1,
 419 -24.4,2.104167
 420
 421 CONTINUE
 422 BOUNDARY CHANGE

423 3,
 424 7,1,1, .000248
 425 8,2,1, .000248
 426 9,3,1, .000248
 427 THERMAL LOADS
 428 1,
 429 -42.6,2.104166
 430
 431 CONTINUE
 432 BOUNDARY CHANGE
 433 3,
 434 7,1,1, .000342
 435 8,2,1, .000342
 436 9,3,1, .000342
 437 THERMAL LOADS
 438 1,
 439 -58.7,2.104167
 440
 441 CONTINUE
 442 BOUNDARY CHANGE
 443 3,
 444 7,1,1, .000420
 445 8,2,1, .000420
 446 9,3,1, .000420
 447 THERMAL LOADS
 448 1,
 449 -72.0,2.104167
 450
 451 CONTINUE
 452 BOUNDARY CHANGE
 453 3,
 454 7,1,1, .000462
 455 8,2,1, .000462
 456 9,3,1, .000462
 457 THERMAL LOADS
 458 1,
 459 -81.8,2.104166
 460
 461 CONTINUE
 462 BOUNDARY CHANGE
 463 3,
 464 7,1,1, .000366
 465 8,2,1, .000366
 466 9,3,1, .000366
 467 THERMAL LOADS
 468 1,
 469 -87.6,2.104167
 470
 471 CONTINUE
 472 BOUNDARY CHANGE
 473 3,
 474 7,1,1, .000373
 475 8,2,1, .000373

476 9,3,1, .000373
 477 THERMAL LOADS
 478 1,
 479 -89.2,2.104167
 480
 481 CONTINUE
 482 BOUNDARY CHANGE
 483 3,
 484 7,1,1, .000362
 485 8,2,1, .000362
 486 9,3,1, .000362
 487 THERMAL LOADS
 488 1,
 489 -86.5,2.104166
 490
 491 CONTINUE
 492 BOUNDARY CHANGE
 493 3,
 494 7,1,1, .000260
 495 8,2,1, .000260
 496 9,3,1, .000260
 497 THERMAL LOADS
 498 1,
 499 -79.6,2.104167
 500
 501 CONTINUE
 502 BOUNDARY CHANGE
 503 3,
 504 7,1,1, .000225
 505 8,2,1, .000225
 506 9,3,1, .000225
 507 THERMAL LOADS
 508 1,
 509 -68.9,2.104167
 510
 511 CONTINUE
 512 BOUNDARY CHANGE
 513 3,
 514 7,1,1, .000070
 515 8,2,1, .000070
 516 9,3,1, .000070
 517 THERMAL LOADS
 518 1,
 519 -54.8,2.104166
 520
 521 CONTINUE
 522 BOUNDARY CHANGE
 523 3,
 524 7,1,1, .000048
 525 8,2,1, .000048
 526 9,3,1, .000048
 527 THERMAL LOADS
 528 1,

529 -38.1,2.104167
 530
 531 CONTINUE
 532 BOUNDARY CHANGE
 533 3,
 534 7,1,1, -.000107
 535 8,2,1, -.000107
 536 9,3,1, -.000107
 537 THERMAL LOADS
 538 1,
 539 -19.5,2.104167
 540
 541 CONTINUE
 542 BOUNDARY CHANGE
 543 3,
 544 7,1,1, .000000
 545 8,2,1, .000000
 546 9,3,1, .000000
 547 THERMAL LOADS
 548 1,
 549 .0,2.104166
 550
 551 CONTINUE
 552 BOUNDARY CHANGE
 553 3,
 554 7,1,1, -.000085
 555 8,2,1, -.000085
 556 9,3,1, -.000085
 557 THERMAL LOADS
 558 1,
 559 19.5,2.104167
 560
 561 CONTINUE
 562 BOUNDARY CHANGE
 563 3,
 564 7,1,1, -.000166
 565 8,2,1, -.000166
 566 9,3,1, -.000166
 567 THERMAL LOADS
 568 1,
 569 38.1,2.104167
 570
 571 CONTINUE
 572 BOUNDARY CHANGE
 573 3,
 574 7,1,1, -.000274
 575 8,2,1, -.000274
 576 9,3,1, -.000274
 577 THERMAL LOADS
 578 1,
 579 54.8,2.104166
 580
 581 CONTINUE

582 BOUNDARY CHANGE
 583 3,
 584 7,1,1, -.000344
 585 8,2,1, -.000344
 586 9,3,1, -.000344
 587 THERMAL LOADS
 588 1,
 589 68.9,2.104167
 590
 591 CONTINUE
 592 BOUNDARY CHANGE
 593 3,
 594 7,1,1, -.000378
 595 8,2,1, -.000378
 596 9,3,1, -.000378
 597 THERMAL LOADS
 598 1,
 599 79.6,2.104167
 600
 601 CONTINUE
 602 BOUNDARY CHANGE
 603 3,
 604 7,1,1, -.000411
 605 8,2,1, -.000411
 606 9,3,1, -.000411
 607 THERMAL LOADS
 608 1,
 609 86.5,2.104166
 610
 611 CONTINUE
 612 BOUNDARY CHANGE
 613 3,
 614 7,1,1, -.000424
 615 8,2,1, -.000424
 616 9,3,1, -.000424
 617 THERMAL LOADS
 618 1,
 619 89.2,2.104167
 620
 621 CONTINUE
 622 BOUNDARY CHANGE
 623 3,
 624 7,1,1, -.000401
 625 8,2,1, -.000401
 626 9,3,1, -.000401
 627 THERMAL LOADS
 628 1,
 629 87.6,2.104167
 630
 631 CONTINUE
 632 BOUNDARY CHANGE
 633 3,
 634 7,1,1, -.000374

635 8,2,1, -.000374
 636 9,3,1, -.000374
 637 THERMAL LOADS
 638 1,
 639 81.8,2.104166
 640
 641 CONTINUE
 642 BOUNDARY CHANGE
 643 3,
 644 7,1,1, -.000246
 645 8,2,1, -.000246
 646 9,3,1, -.000246
 647 THERMAL LOADS
 648 1,
 649 72.0,2.104167
 650
 651 CONTINUE
 652 BOUNDARY CHANGE
 653 3,
 654 7,1,1, -.000201
 655 8,2,1, -.000201
 656 9,3,1, -.000201
 657 THERMAL LOADS
 658 1,
 659 58.7,2.104167
 660
 661 CONTINUE
 662 BOUNDARY CHANGE
 663 3,
 664 7,1,1, -.000100
 665 8,2,1, -.000100
 666 9,3,1, -.000100
 667 THERMAL LOADS
 668 1,
 669 42.6,2.104166
 670
 671 CONTINUE
 672 BOUNDARY CHANGE
 673 3,
 674 7,1,1, .000146
 675 8,2,1, .000146
 676 9,3,1, .000146
 677 THERMAL LOADS
 678 1,
 679 24.4,2.104166
 680
 681 CONTINUE
 682 BOUNDARY CHANGE
 683 3,
 684 7,1,1, .000030
 685 8,2,1, .000030
 686 9,3,1, .000030
 687 THERMAL LOADS

688 1,
 689 5.1,2.104168
 690
 691 CONTINUE
 692 BOUNDARY CHANGE
 693 3,
 694 7,1,1, .000000
 695 8,2,1, .000000
 696 9,3,1, .000000
 697 THERMAL LOADS
 698 1,
 699 .0,2.104166
 700
 701 CONTINUE
 702 BOUNDARY CHANGE
 703 3,
 704 7,1,1, .000000
 705 8,2,1, .000000
 706 9,3,1, .000000
 707 THERMAL LOADS
 708 1,
 709 .0,2.104166
 710
 711 CONTINUE
 712 BOUNDARY CHANGE
 713 3,
 714 7,1,1, .000000
 715 8,2,1, .000000
 716 9,3,1, .000000
 717 THERMAL LOADS
 718 1,
 719 .0,2.104168
 720
 721 CONTINUE
 722 BOUNDARY CHANGE
 723 3,
 724 7,1,1, .000000
 725 8,2,1, .000000
 726 9,3,1, .000000
 727 THERMAL LOADS
 728 1,
 729 .0,2.104166
 730
 731 CONTINUE
 732 BOUNDARY CHANGE
 733 3,
 734 7,1,1, .000000
 735 8,2,1, .000000
 736 9,3,1, .000000
 737 THERMAL LOADS
 738 1,
 739 .0,2.104166
 740

741 CONTINUE
 742 BOUNDARY CHANGE
 743 3,
 744 7,1,1, .000000
 745 8,2,1, .000000
 746 9,3,1, .000000
 747 THERMAL LOADS
 748 1,
 749 .0,2.104168
 750
 751 CONTINUE
 752 BOUNDARY CHANGE
 753 3,
 754 7,1,1, .000000
 755 8,2,1, .000000
 756 9,3,1, .000000
 757 THERMAL LOADS
 758 1,
 759 .0,2.104166
 760
 761 CONTINUE
 762 BOUNDARY CHANGE
 763 3,
 764 7,1,1, .000000
 765 8,2,1, .000000
 766 9,3,1, .000000
 767 THERMAL LOADS
 768 1,
 769 .0,2.104166
 770
 771 CONTINUE
 772 BOUNDARY CHANGE
 773 3,
 774 7,1,1, .000000
 775 8,2,1, .000000
 776 9,3,1, .000000
 777 THERMAL LOADS
 778 1,
 779 .0,2.104168
 780
 781 CONTINUE
 782 BOUNDARY CHANGE
 783 3,
 784 7,1,1, .000000
 785 8,2,1, .000000
 786 9,3,1, .000000
 787 THERMAL LOADS
 788 1,
 789 .0,2.104166
 790
 791 CONTINUE
 792 BOUNDARY CHANGE
 793 3,

794 7,1,1, .000000
 795 8,2,1, .000000
 796 9,3,1, .000000
 797 THERMAL LOADS
 798 1,
 799 .0,2.104166
 800
 801 CONTINUE
 802 BOUNDARY CHANGE
 803 3,
 804 7,1,1, .000000
 805 8,2,1, .000000
 806 9,3,1, .000000
 807 THERMAL LOADS
 808 1,
 809 .0,2.104168
 810
 811 CONTINUE
 812 BOUNDARY CHANGE
 813 3,
 814 7,1,1, .000000
 815 8,2,1, .000000
 816 9,3,1, .000000
 817 THERMAL LOADS
 818 1,
 819 .0,2.104166
 820
 821 CONTINUE
 822 BOUNDARY CHANGE
 823 3,
 824 7,1,1, .000000
 825 8,2,1, .000000
 826 9,3,1, .000000
 827 THERMAL LOADS
 828 1,
 829 .0,2.104166
 830
 831 CONTINUE
 832 BOUNDARY CHANGE
 833 3,
 834 7,1,1, .000000
 835 8,2,1, .000000
 836 9,3,1, .000000
 837 THERMAL LOADS
 838 1,
 839 .0,2.104168
 840
 841 CONTINUE
 842 BOUNDARY CHANGE
 843 3,
 844 7,1,1, .000000
 845 8,2,1, .000000
 846 9,3,1, .000000

847 THERMAL LOADS
 848 1,
 849 .0,2.104166
 850
 851 CONTINUE
 852 BOUNDARY CHANGE
 853 3,
 854 7,1,1, .000000
 855 8,2,1, .000000
 856 9,3,1, .000000
 857 THERMAL LOADS
 858 1,
 859 .0,2.104166
 860
 861 CONTINUE
 862 BOUNDARY CHANGE
 863 3,
 864 7,1,1, .000000
 865 8,2,1, .000000
 866 9,3,1, .000000
 867 THERMAL LOADS
 868 1,
 869 .0,2.104168
 870
 871 CONTINUE
 872 BOUNDARY CHANGE
 873 3,
 874 7,1,1, .000000
 875 8,2,1, .000000
 876 9,3,1, .000000
 877 THERMAL LOADS
 878 1,
 879 .0,2.104166
 880
 881 CONTINUE
 882 BOUNDARY CHANGE
 883 3,
 884 7,1,1, .000027
 885 8,2,1, .000027
 886 9,3,1, .000027
 887 THERMAL LOADS
 888 1,
 889 -5.1,2.104166
 890
 891 CONTINUE
 892 BOUNDARY CHANGE
 893 3,
 894 7,1,1, .000131
 895 8,2,1, .000131
 896 9,3,1, .000131
 897 THERMAL LOADS
 898 1,
 899 -24.4,2.104168

900
 901 CONTINUE
 902 BOUNDARY CHANGE
 903 3,
 904 7,1,1, .000248
 905 8,2,1, .000248
 906 9,3,1, .000248
 907 THERMAL LOADS
 908 1,
 909 -42.6,2.104166
 910
 911 CONTINUE
 912 BOUNDARY CHANGE
 913 3,
 914 7,1,1, .000342
 915 8,2,1, .000342
 916 9,3,1, .000342
 917 THERMAL LOADS
 918 1,
 919 -58.7,2.104166
 920
 921 CONTINUE
 922 BOUNDARY CHANGE
 923 3,
 924 7,1,1, .000420
 925 8,2,1, .000420
 926 9,3,1, .000420
 927 THERMAL LOADS
 928 1,
 929 -72.0,2.104166
 930
 931 CONTINUE
 932 BOUNDARY CHANGE
 933 3,
 934 7,1,1, .000462
 935 8,2,1, .000462
 936 9,3,1, .000462
 937 THERMAL LOADS
 938 1,
 939 -81.8,2.104166
 940
 941 CONTINUE
 942 BOUNDARY CHANGE
 943 3,
 944 7,1,1, .000366
 945 8,2,1, .000366
 946 9,3,1, .000366
 947 THERMAL LOADS
 948 1,
 949 -87.6,2.104166
 950
 951 CONTINUE
 952 BOUNDARY CHANGE
 953 3,
 954 7,1,1, .000373
 955 8,2,1, .000373

956 9,3,1, .000373
 957 THERMAL LOADS
 958 1,
 959 -89.2,2.104168
 960
 961 CONTINUE
 962 BOUNDARY CHANGE
 963 3,
 964 7,1,1, .000362
 965 8,2,1, .000362
 966 9,3,1, .000362
 967 THERMAL LOADS
 968 1,
 969 -86.5,2.104166
 970
 971 CONTINUE
 972 BOUNDARY CHANGE
 973 3,
 974 7,1,1, .000260
 975 8,2,1, .000260
 976 9,3,1, .000260
 977 THERMAL LOADS
 978 1,
 979 -79.6,2.104166
 980
 981 CONTINUE
 982 BOUNDARY CHANGE
 983 3,
 984 7,1,1, .000225
 985 8,2,1, .000225
 986 9,3,1, .000225
 987 THERMAL LOADS
 988 1,
 989 -68.9,2.104168
 990
 991 CONTINUE
 992 BOUNDARY CHANGE
 993 3,
 994 7,1,1, .000070
 995 8,2,1, .000070
 996 9,3,1, .000070
 997 THERMAL LOADS
 998 1,
 999 -54.8,2.104166
 1000
 1001 CONTINUE
 1002 BOUNDARY CHANGE
 1003 3,
 1004 7,1,1, .000048
 1005 8,2,1, .000048
 1006 9,3,1, .000048
 1007 THERMAL LOADS
 1008 1,
 1009 -38.1,2.104166
 1010
 1011 CONTINUE